

TRANSPORTATION GENERALIZED COST
FUNCTIONS FOR RAILROADS AND INLAND
WATERWAYS

By

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ABSTRACT

The purpose of this thesis is to design the functional form of unimodal generalized cost functions, for railroads and inland waterways. These are the sum of the fraction of operators' costs which are passed on to users of transportation services and of actual users' costs: trip-time, unreliability, loss and damage. The basic entity to which generalized cost functions apply is a combination of a mode, a link, a commodity and possibly a user group. Consequently, costs have to be allocated at this disaggregate level. These functions are the basis of the equilibration procedure on the multi-modal network based on entropy maximization and cost minimization. Now the purpose of such a multi-modal model is to test a broad spectrum of transportation policies, concerning mainly investments, operations, maintenance and regulations. Therefore, unimodal models and particularly cost functions must be explicitly policy sensitive. Besides they must provide a framework for a detailed link analysis of investment needs, accounting, maintenance and deterioration which must be done once flows are known. Because of its flexibility and its ability to evaluate operations and to incorporate policy sensitive variables, the engineering approach was chosen: through a simulation process, transportation activities are decomposed into basic units for which costs can be quantified accurately. The study showed the importance of the trade-off between policy sensitive modelling on one hand, and computational ease, data requirements and analytical accuracy on the other hand.

Thesis Supervisor: Fred Moavenzadeh, Professor of Civil Engineering.

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I want to dedicate this thesis to my grandfather who, unfortunately, will not be able to see it.

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CHAPTER I

INTRODUCTION:

The fundamental paradigm of transportation systems analysis can be defined by the interrelations between three major components: (1)

A. The activity system, i.e. the pattern of social and economic activities.

T: the transportation system.

F: the pattern of flows within the transportation system.

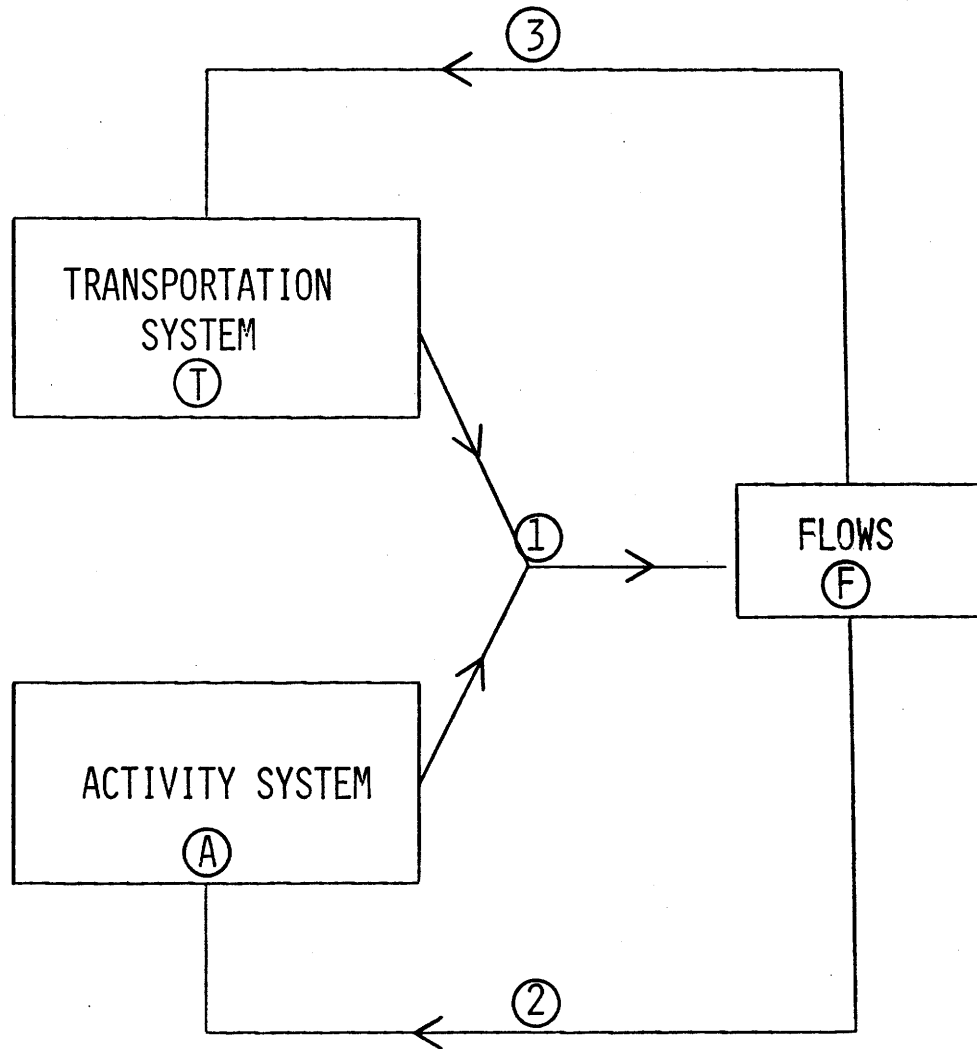
There are three major relationships which are summarized in Figure 1:

"type 1": the flow pattern in the transportation system is determined by both the transportation system ("supply side") and the activity system ("demand side") in a point of equilibrium between supply and demand.

"type 2": the current flow pattern will result in changes in the activity system since new social and economic activities will be able to take place nearby transportation areas.

"type 3": the current flow pattern will induce a supply response to anticipated changes in flows.

Figure 1
The Fundamental
Transportation System Paradigm



The main purpose of a multi-modal intercity transportation model is twofold:

- On one hand to provide the various actors of "the type 3" relationship with an analytical tool likely to lead them to the optimal decision as regards changes in the transportation system.
- On the other hand to investigate and try and quantify the "type 1" relationship, through an equilibrium analysis.

Activity shifts models, which attempt to describe the "type 2" relationship, so far, have been more difficult to build and use, because of the complexity and the magnitude of the effects involved. Since transportation is used as an intermediate good in nearly all industries and regions, changes within the transportation system will obviously alter the allocation of economic activity and consequently the level of income and employment among regions and industries. At least at a qualitative level, transportation planners must keep this idea in mind when considering transportation policies.

The very close relationship between transportation flows and the level of the economic activity is clearly shown by the comparison of transport facilities among differently developed countries: (2)

- West Germany: 135 km. of paved road/100 km²
- Mexico: 2.2 km.
- Paraguay: .1 km.

Consequently, while in developed countries the focus is on optimal management of existing facilities (TSM: Transportation system management), in less developed countries the main issue is the investment policy in the transportation sector.

Now a key element of the evaluation of transportation policies is the subsequent flows. Therefore these are the major output of such a model, and become in turn the inputs of the evaluation procedure involving both transportation modellers and decision makers.

1. General structure of the model and main features.

The main actor of the "type 3" relationship is often an agency depending on the government of the country considered. The purpose of the model described here is to provide the Egyptian transport planning authority with an analytical tool able to help it evaluate different transportation policies. Therefore the first component of the model is a "policy block" involving the two major tools of the government:

- market regulations: essentially related to entry, exit, mergers, prices, taxes, subsidies, rate of return.
- operating regulations: concerning the service level, equipment, labor, environment.

Market regulations will obviously mainly impact market structure, while operating regulations will impact investment strategies in the transportation sector. But there are cross relationships: the market structure

will be a determinant of the scale and goals of investments; reciprocally operating regulations can result in a change in the market structure (e.g., the inability of a firm to meet service requirements can result in a merger of a looser form of cooperation).

The market structure and the investments in the transport sector will change the cost of transportation as perceived by users of a mode. Specific features of various modes oblige to investigate this relationship within a unimodal framework. Unimodal user's costs will be the input of the equilibration procedure within the multimodal network, which will produce the final traffic assignment. Transport flows will be the output of the equilibration procedure which aims at selecting a set of desirable investments, according to criteria expressed by decision-makers and quantified, when possible within the model. Besides flows will allow to make a unimodal link detailed analysis which should result in "microscale" management options or investment decisions. The whole structure of the model is summarized in Figure II.

The purpose of this study is to investigate the impact of investments and operating regulations on transportation costs as they are perceived by the users of a given mode on a given link. This subset of the whole structure is shown in Figure III.

The main features of the model are:

- multi-modal: since obviously the transportation part of the logistics choice compares all modes, except in the case of

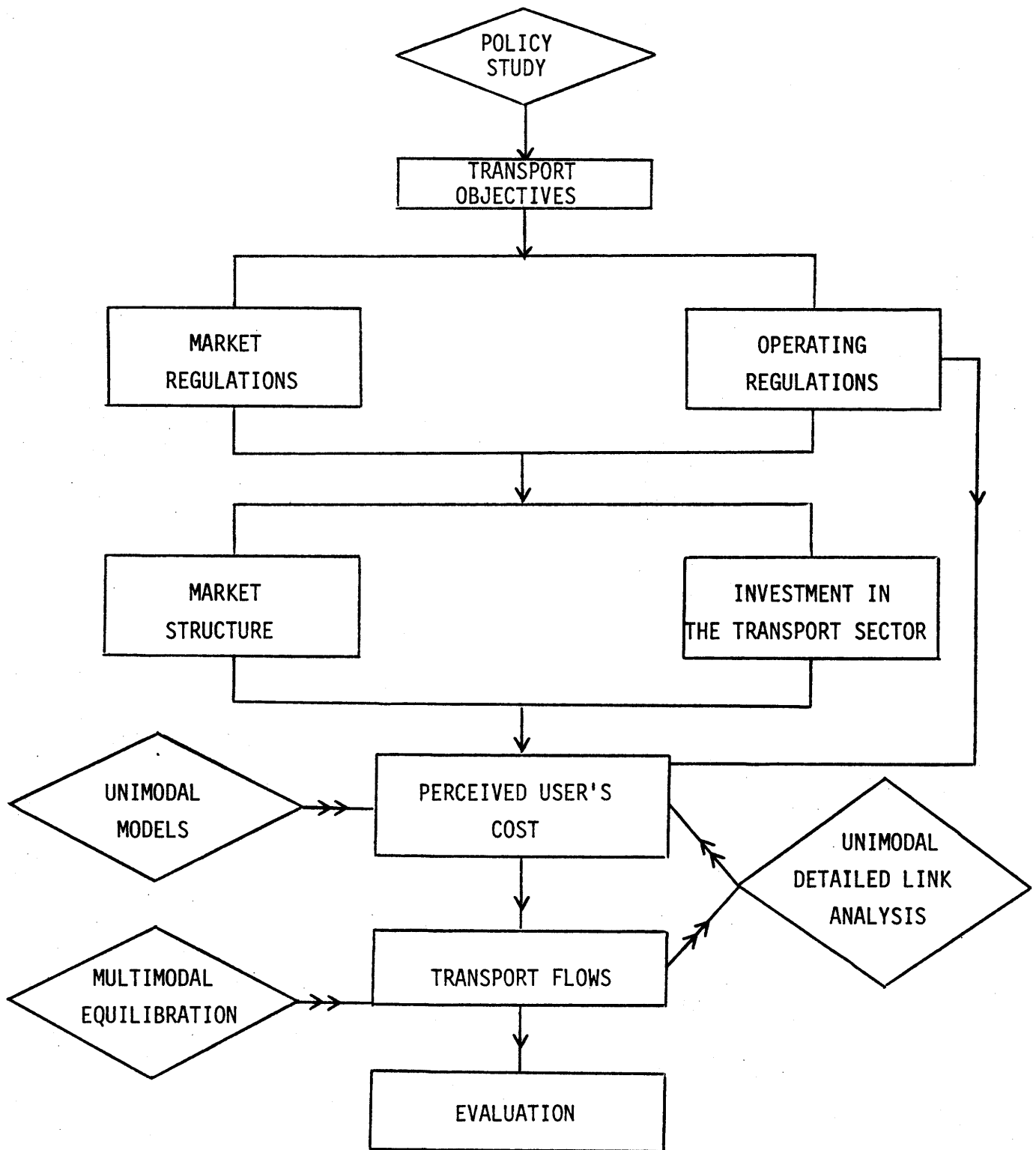
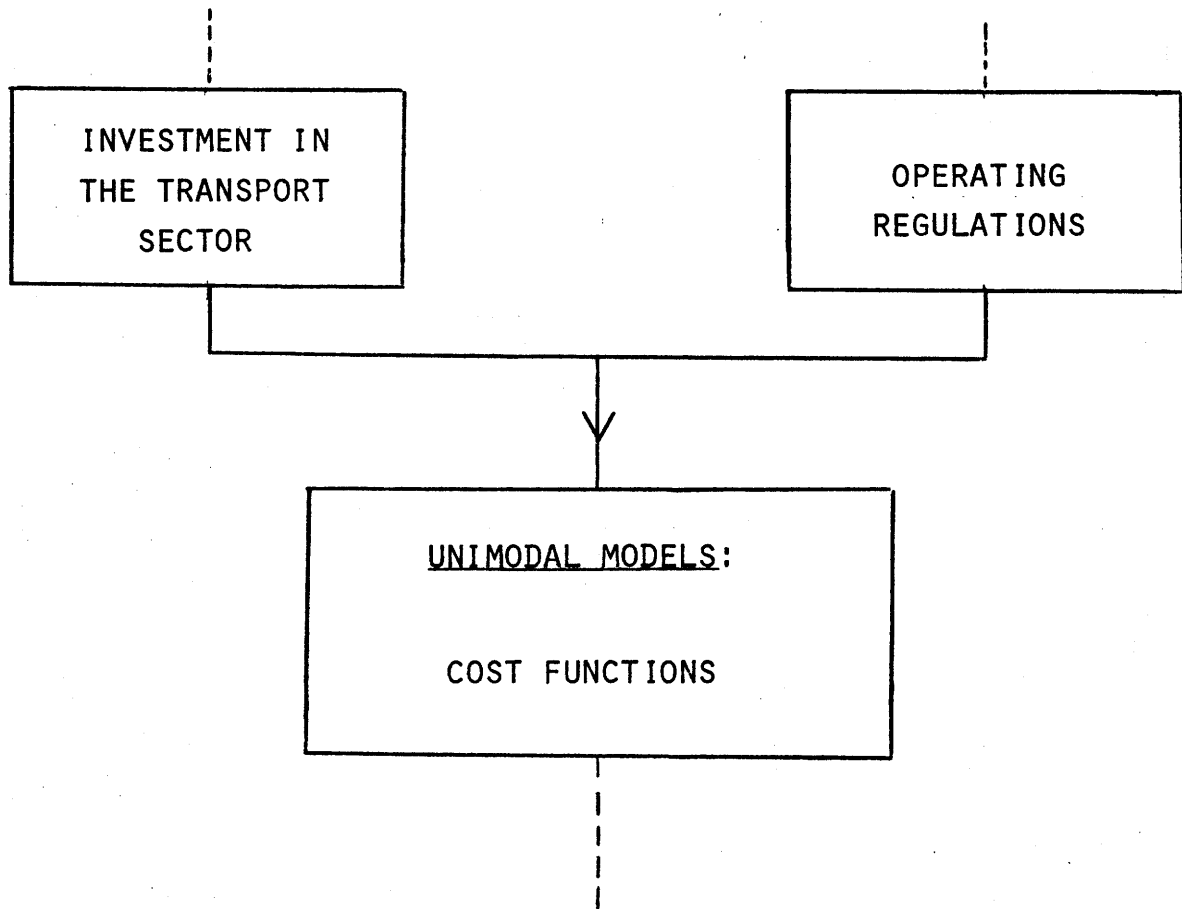


Figure II

General Framework of the Model.

FIGURE III

The Scope of This Thesis



modal captive users, the provision of flows must be multi-modal. But still a necessary first step is a good understanding of modal operations and costing and the last step should be a detailed mode specific link analysis to update costs and evaluate alterations due to flow dependent cost components.

- multi-criteria evaluation: "type 2" relationship can hardly be reduced to purely economic costs or benefits, because of obvious qualitative or external impacts. The summary of investment options through a single net present value of benefit must not be the only criterion. Decision-makers must be aware of the allocation of costs and benefits among the various actors who are potentially impacted by projects. Multi-criteria evaluation is a way of analyzing the trade-offs among various criteria, expressed by decision-makers and quantified, if possible by transportation modellers.
- policy sensitive: a fundamental requirement of such a model is to be able to take into account and to differentiate clearly policies which are to be evaluated. The implications of such an ability will be discussed more thoroughly in the following section.

2. Policy sensitivity.

i. Literature Review.

Typical examples have been chosen. This is certainly not

an exhaustive description of the state of the art in this matter. Before describing those transportation models in the light of policy sensitivity, a remark must be done. There are two distinct aspects of policy-sensitivity within a model:

1. adequate policy-sensitive variables: they must obviously be taken into account explicitly within the model.
2. an analytical way of relating the quantitative values of those variables to various policies: This is the very challenge of policy sensitivity. In most cases, judgement, experience or qualitative considerations lead to an approximate evaluation of policy sensitive variables. Every time it is possible, causal relationships between policy options and quantitative values must be determined and modelled, through an analytical procedure. When it is not possible, a hypothetized value should be carefully tested before being used for further calculations.

a. HARVARD-BROOKINGS MODEL: (3)

The general structure of the model is described in Figure IV. The purpose of this ambitious project was to model and quantify "type 1" and "type 2" relationships pointed above. A macroeconomic model was then used jointly with a pure transportation model, hopefully able to test various scenarios in both fields and their interactions.

The first problem that arises is definitely related to point 2 mentioned in the previous section. Most policies are dealt with through

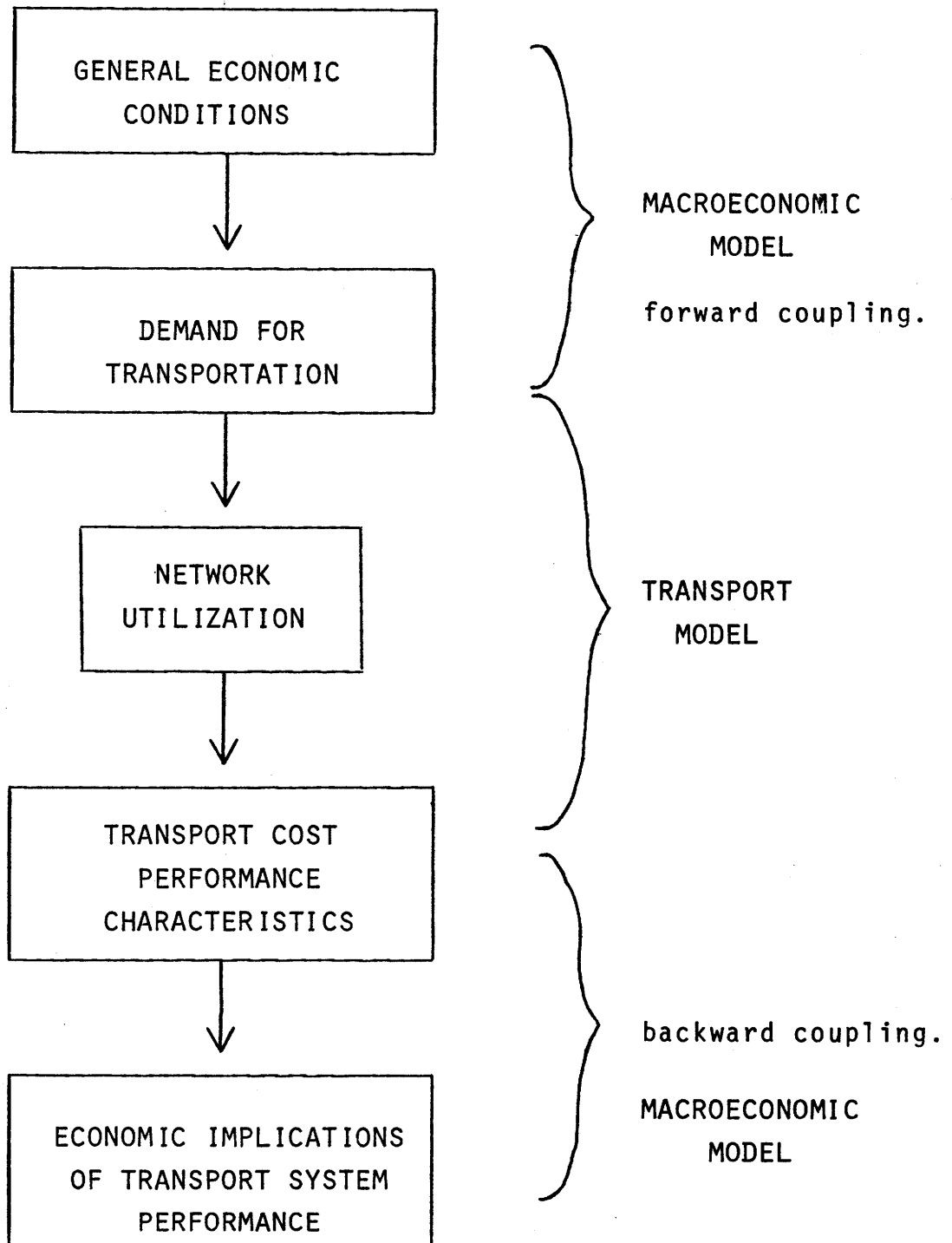


FIGURE IV
General Structure of the Harvard-Brookings Model.

changes in user specified gross parameters, which are empirically adjusted. The cost of experimental runs of the whole model to test those values makes this approach highly questionable. Besides the joint use of a macro-economic model seems to be dangerous since the inputs of the transportation model can convey errors inherent to any modelling effort. Anyway the model contains most relevant policy sensitive variables, except those related to the organizational and regulatory environments, but in several cases they are too much aggregated, and should be broken in various components that can be independently impacted by different policies. Besides a technical shortcoming of the model is certainly the all or nothing assignment of each point to point commodity move, using a deterministic and normative procedure, which can lead to a very high sensitivity of flows to minor changes within the network. This phenomenon is aggravated by the use of discrete values of the commodity performance values, aggregated over all shippers (i.e., dollar value placed on the various components of the perceived user's cost: time, reliability, loss and damage). At last the model was to some extent conceived as a "black box" giving predicted link flows. There was no explicit interaction between policy-issues and the various steps of the modelling procedure.

b. MEYER, PECK, STENASON, ZWICK: The economics of competition in the transportation industry. (4)

The main purpose of this research was to describe the impact of regulations on the economic efficiency of the freight transportation system. The procedure was to use a comparison among the costs of the

various modes. However very strong and questionable assumptions were made among which:

- aggregation over all commodities is realistic.
- the relevant cost to consider is the marginal cost.
- inventory costs are only determined by shipment size, average travel-time and average commodity value.

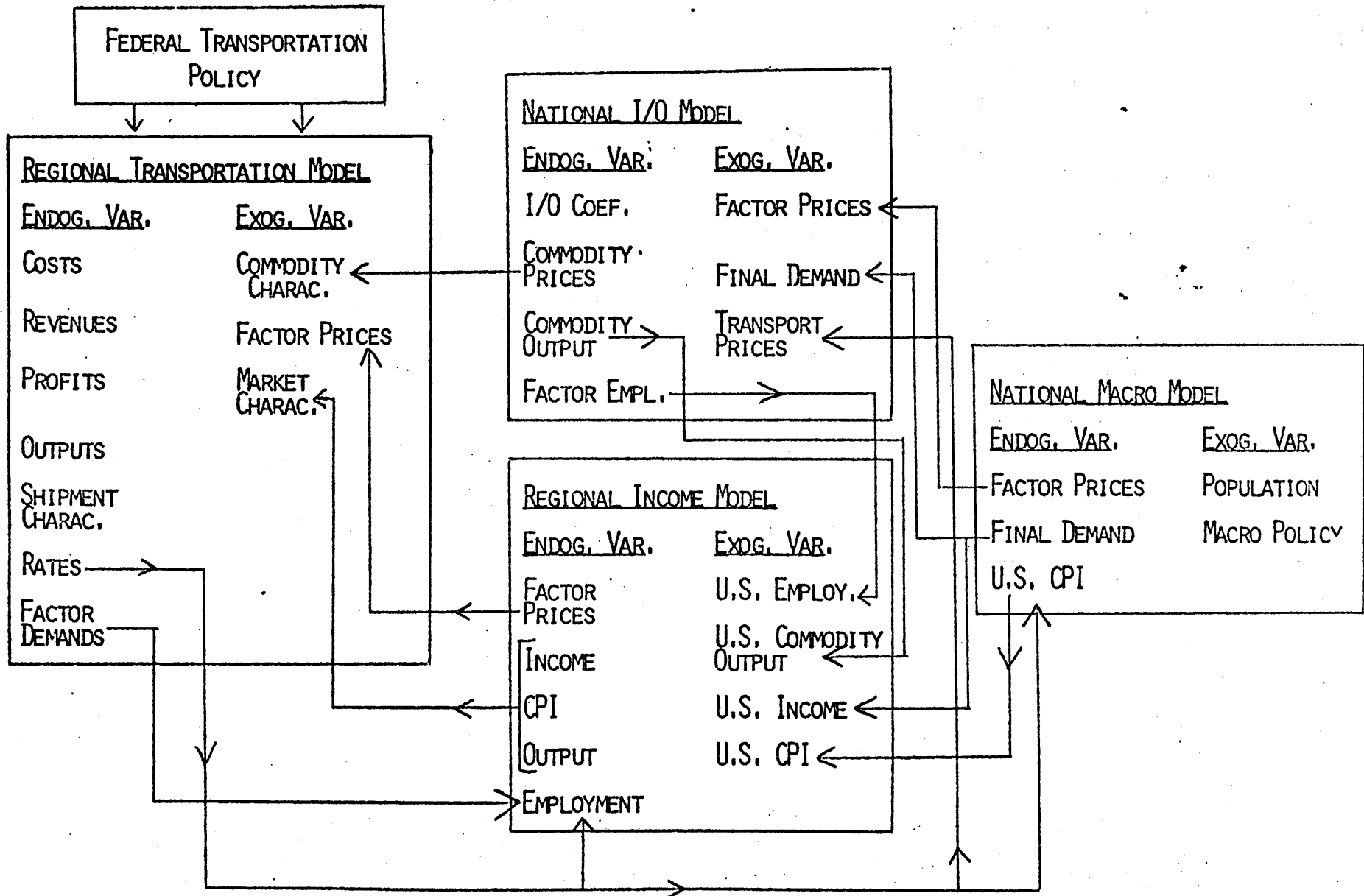
The impact of regulation, an incomplete modal choice model, and an excessive aggregation led to very questionable results. Besides the crucial importance of reliability in inventory policy was totally neglected, although it is certainly a major component if not the only one. The issue of marginal costs as a basis of freight rates was actually the only interference of policy issues within the model. It illustrates what we might call an excessive microeconomic bias at the expense of more pragmatic and detailed observations of the transportation sector.

c. ANN F. FRIEDLAENDER: An integrated policy model for the surface freight transportation industries. (5)

This model is a very broad attempt of modelling the whole transportation system paradigm thanks to a set of models likely to quantify the interrelations between policy, transportation, national economy and regional income. The general structure is shown in Figure V. The basic sub-models involved are:

FIGURE V

AN INTEGRATED POLICY MODEL FOR THE TRANSPORTATION INDUSTRIES



- a regional transportation model
- a regional income model
- a national interindustry model
- a small scale national macroeconomic model.

A full solution of the model is theoretically obtainable through a simultaneous determination.

The transportation sector involves the following endogenous variables: costs, revenues, profits, outputs, shipment characteristics, rates, factors demand.

A whole set of assumptions about the market structure and the behavior of firms, as represented by the objective function can be incorporated to the model. This theoretical tool is then very powerful, since it can take into account a broad spectrum of transportation policies. A very interesting classification is done within the model. Policies are classified according to the impact they have on major economic functions:

- demand function
- market structure
- cost function

A set of the most important examples is given on Figure VI. The aggregation framework is the following:

FIGURE VI

Impacts of Policies on Economic Functions

	<u>Demand Function</u>	<u>Market Structure</u>	<u>Cost Function</u>
Permissible Price Discrimination	X	-	-
Setting Rate Levels	X	-	-
Total Rate Deregulation	X	X	-
Elimination of Rate Bureaus	X	X	-
Entry Controls	X	X	-
Subsidies	-	-	X
Energy Policy	-	-	X
User Charges	-	-	X
Abandonment	-	-	X
Union Work Rules	-	-	X
Provision of Infrastructure	-	-	X
Weight and Size Limitations	-	-	X
Roadbed Nationalization	-	-	X
Mergers and Consolidation	X	X	X

1. durable manufacturers
2. non-durable manufacturers
3. grains
4. other agricultural products
5. chemicals, minerals and others
6. coal
7. petroleum products.

Undoubtedly the calibration and estimation of such a broad modelling framework arise many problems. Some of them are theoretical, connected with behavioral assumptions of various actors, and the specification of transportation cost functions. (A thorough analysis of this problem will be made in the following chapter.) Many others are statistical and related to the huge volume of data required. The very close interrelations among the various models involved, as well as the aggregation level make the accuracy of specific transportation results highly questionable. But still the theoretical framework is very interesting since it actually takes into account all the components of the transportation systems analysis paradigm and potentially can study a very wide spectrum of policies.

d. ROBERTS, BEN-AKIVA, TERZIEV, YU-SHENG CHIANG; Development of a policy-sensitive model for forecasting freight demand. (6)

The main characteristics of this model are:

- disaggregate: the logistics decision-making process at the level

of a group of firms is the basis of the model.

- probabilistic: cost functions include an error term and the functional form of the demand model is either logit or probit
- explanatory: the key explanatory variables are summarized in Figure VII. They are the attributes of service, commodity, market and shipper.

A decision of the shipper is represented by the combination of a mode and a shipment size, determined by their probability distributions. A very interesting feature of this model is definitely the consideration of shipment size as a key decision variable.

Policy sensitivity within the model is introduced through the level of service attributes. This is definitely a shortcoming of the model, a lack of the second component of policy sensitivity as described before. The impact of any policy option is only a change in service attributes. Although the authors mention the need for a sophisticated supply side analysis, no hint is given about it. Now, obviously the connection between policy decisions and a quantitative change in the level of service is very difficult to handle. This problem is not dealt with in this paper, which is, in any case, but a first conceptual approach.

e. OTHER EXAMPLES: another type of model deals with problems of a much smaller scale; for example the specific study of a market pair, or of competition between two specific modes. Some of these models deal with

FIGURE VII

Key Variables in Freight Demand

$$V_{ijmq}^k = f(T, C, M, R)$$

V = volume of freight flow
 k = commodity type
 i = origin
 j = destination
 q = shipment size
 m = mode

T
Transport Level
Of Service Attributes

wait time
 travel time
 delivery reliability
 loss and damage
 tariff
 minimum shipment size
 special services
 packaging cost
 handling cost

C
Commodity
Attributes

value
 shelf life
 seasonality
 density
 perishability

M
Market Attributes
(at potential origins)

price
 quality
 availability
 production rate

R
Receiver Attributes
(at the destination end)

use rate
 variability in use rate
 stockout situation
 reorder cost
 capital carrying cost
 risk of stockout

policy options, but generally without any modelling framework of their impact on transportation flows.

- P.O. ROBERTS, ET AL.: TOFC Shuttle trains, a study in equilibrium analysis, analysis of the incremental costs and tradeoffs between energy efficiency and physical distribution effectiveness in intercity freight markets; TOFC versus COFC, a comparison of technology. (7),(8),(9).

Basically within the same framework, P.O. Roberts and several joint authors have dealt with specific issues in transportation at what we might call a micro-scale level, typically a city-pair and two modes. One of the main issues is the impact of transportation policies on fuel consumption. The basic feature of the model is the assumption that the shipper's behavior is to try and minimize his logistics cost which is the sum of purchase cost, order cost, transport cost, storage cost, capital carrying cost and stockout cost. The paradigm is summarized in Figure VIII. An aggregation procedure is then used to determine aggregate flows in the network, through sampling, as shown in Figure IX. Again in this framework, the basic reproach would be that policy impacts are not modelled but are merely represented by changes in the level of service or in pricing. But several rules of the thumb and a great deal of judgement in a very interactive process allowed the authors to derive very interesting results at the scale of a city-pair. The consideration of the firm as the basic decision-making unit and the subsequent aggregation procedure seem to prevent from applying such concepts to a global transportation system, mainly because of huge data requirements.

FIGURE VIII.

CHOICE VARIABLES WHICH CAN BE USED TO MINIMIZE LOGISTICS COSTS
TO THE INDIVIDUAL BUSINESS ESTABLISHMENT

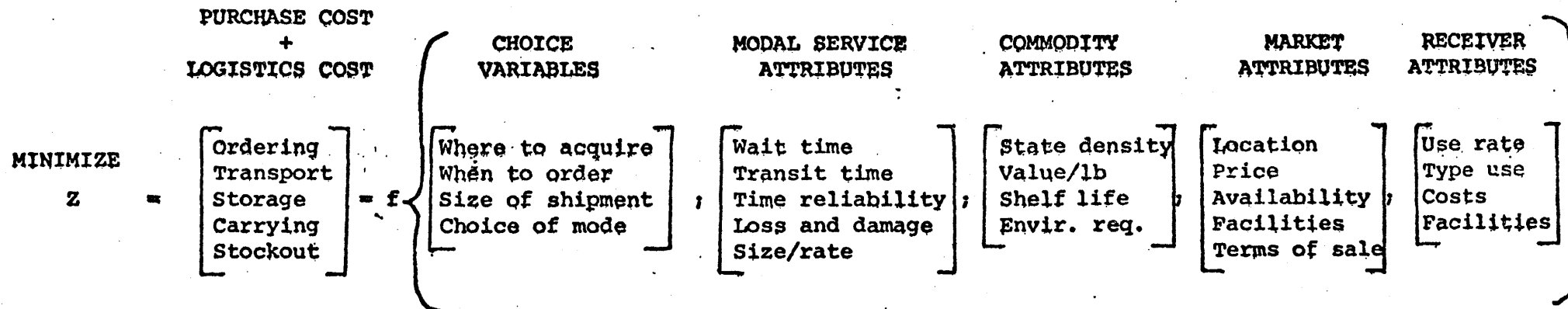
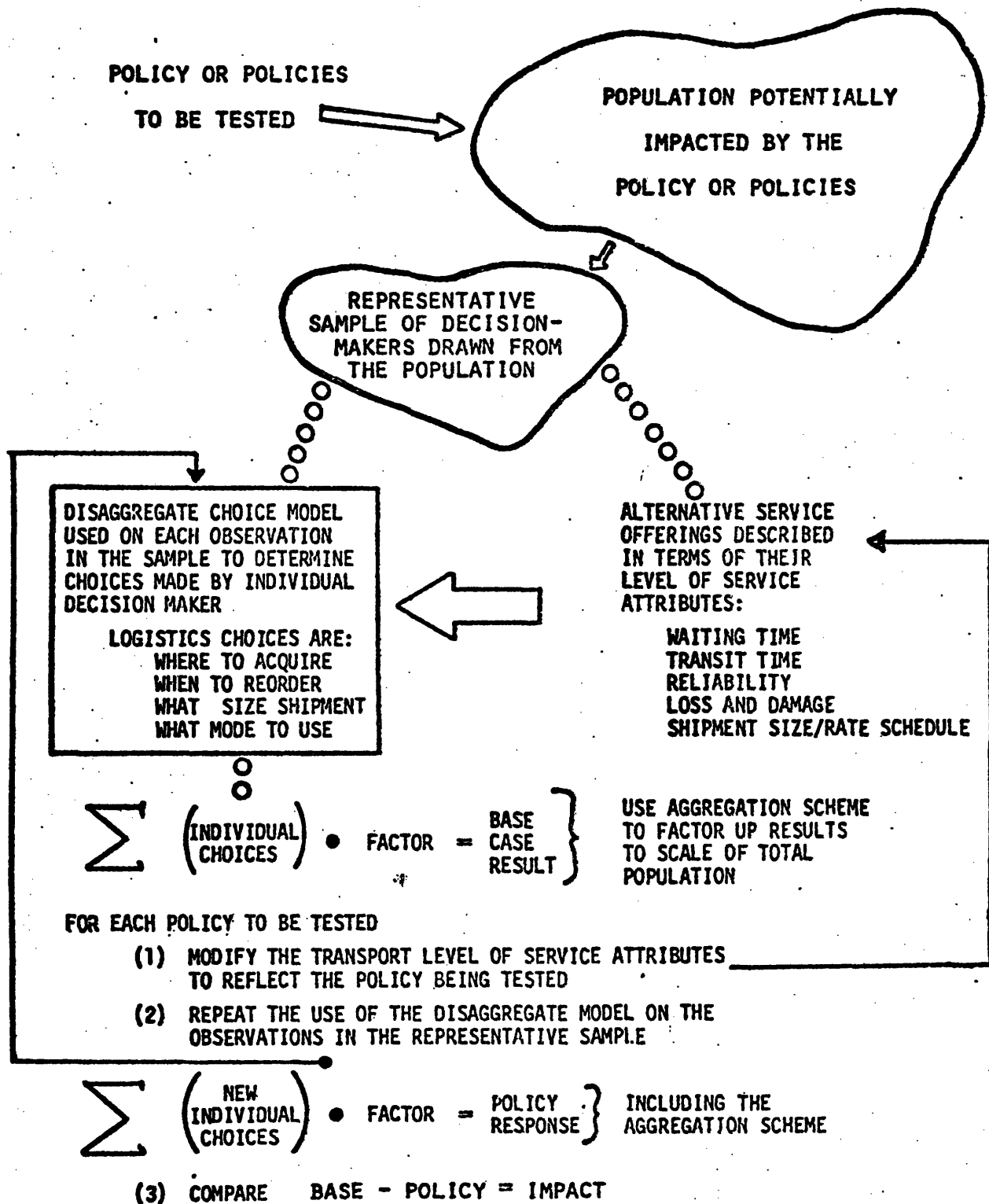


FIGURE IX
DEMAND SIDE ANALYSIS



ii. Summary and conclusions.

With the exception of A. Friedlaender's model, we have seen that most models mentioned above, although dealing with policy options, and often with a great efficiency, often lack analytical tools to quantify the impacts of those options on relevant transportation variables. This is definitely the major stumbling block of policy sensitivity within a model. Still the somewhat empirical and judgemental way of solving the problem, through an exogenous change in user-specified parameters, allows to obtain at least relevant trends in the evolution of transportation systems; besides in many cases, there is obviously no way of dealing more systematically with policy issues.

iii. Classification of policy issues.

In the light of this literature review, it is interesting to try and classify policy-issues related to the transportation sector. There are four main features which can be interesting, with respect to a modelling approach:

- modellable/non-modellable:

A perfectly modellable policy issue must have two characteristic features. It can be represented by explicit variables within the model on one hand; impacts of this issue on these variables can be quantified through a systematic modelling procedure on the other hand. Typical policies of this type are related to investment policy in rolling stock or track in the railroad case. A trip-time model enables to relate those investments to changes

in the level of service.

- implicit/explicit:

A transportation policy is not always formulated very clearly by public authorities. A study of the US transportation policy (The rationale and scope of federal transportation policy. A. Friedlaender et al ()) concluded that it had three major implicit goals which were:

- fairness
- support of rural and agricultural interests
- industry stability.

The discovery of implicit goals allows to capture the coherence of the whole policy and consequently to model it much more efficiently.

- related to the transport sector/not:

Because of "type 1" relationships, issues related to the activity system can have an impact on transportation flows in the network. Therefore there should be a very broad consideration of policy issues, even if, "a priori" they are not specifically related to the transport sector (economic goals, environmental policy, employment policy).

- within the control of transportation planning authorities (TPA)/not:

Major policies, such as energy policy, environmental policy or

consideration of minorities such as elderly and handicapped are constraints imposed upon transportation planning authorities. Therefore they obviously have an impact on the way the transportation system works, and consequently must be explicitly taken into account, as exogenous elements.

CHAPTER II

UNIMODAL SUBCOMPONENT OF THE MODEL

Introduction

In the previous chapter, it has been pointed that a specific unimodal study was the necessary first step of the multi-modal model. This study has two main specific areas of interest, and two subsequent specific sets of outputs:

- (i) The first area can be in turn divided into two major components:
 - On one hand the analysis of actual operations on unimodal networks, mainly through a simulation process. Operations will be decomposed in basic units, for which both resources consumed and relevant outputs can be clearly identified and quantified. The level of detail of such a decomposition should be the result of a trade-off between accuracy and data requirements. The basic entity considered will be a combination of a link, a mode, a commodity and possibly a user-group.
 - On the other hand to be able to relate these fundamental operational units to costs.

The actual determination of these costs will be the preliminary step of the multimodal equilibration procedure. They will obviously be impacted

by the environment in areas such as investment, organization, regulations and technology. Besides, of course the present situation of the network will be a major input of this part of unimodal studies.

The equilibration procedure will be based on a generalized cost minimization among the various combinations of modes and paths, available on the multimodal network. The analytical tool of this process will be the generalized cost-function, which will be described in the second section of this chapter. Its analytical formulation is the basic focus of this thesis.

(ii) The second purpose of unimodal models is the detailed analysis, on a link basis, of the impacts of flows, as determined by the traffic assignment, upon owners, users and operators of the unimodal networks. These impacts are related to three main areas:

- The level of service: it is mainly summarized by attributes such as average trip-time, reliability, loss and damage and rates.
- The physical status of the system: in terms of investment options to adjust supply to demand; of maintenance policy either related to periodic routine works or to flow-dependent damages. At last the actual system deterioration will have to be described explicitly.

- The financial situation of transportation firms involved: an accounting procedure will have to describe it in terms of revenues, costs, profits or losses, subsequent needs for subsidies or tariff adjustment.

These outputs will be described more precisely in the third part of this chapter.

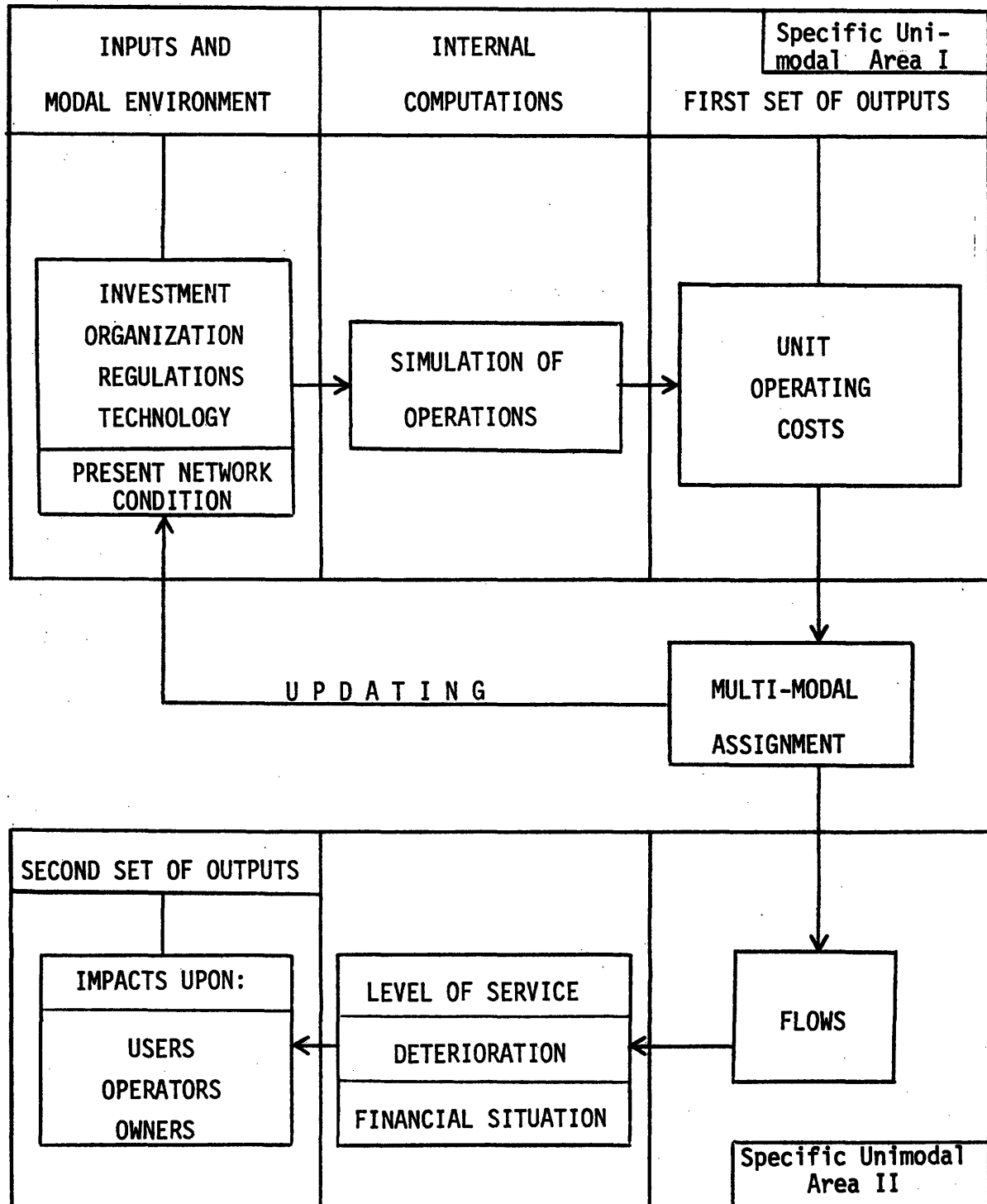
Now the basic structure of any model can be described by three major components:

- inputs: They constitute the set of required data. In this case they are related to links (construction, maintenance, physical characteristics), to vehicles and commodities. They include both physical amounts and unit costs.
- internal computations: this is the very core of the model. It involves functional relationships between inputs, likely to produce relevant figures related to the transportation system.
- outputs: The quantified results of internal computations are related to the three major areas mentioned above.

The basic structure of unimodal models is summarized on Figure X, describing their two specific areas of interest, as an input to the equilibration procedure on one hand, and using its results on the other hand.

Now the "highway cost model" provides a general framework for a

FIGURE X
General Structure of
Unimodal Models



first unimodal study. Although it requires some transformations, namely some simplifications to be adapted to the specific needs of the Intercity Project, it gives a good illustration of the basic concepts described before. Therefore it will be used as an example in the following sections of this chapter. Obviously each mode will require a specific treatment. But, still, the underlying logic will be the same. Figure XI gives the major components of the unimodal road model (URM). (10)

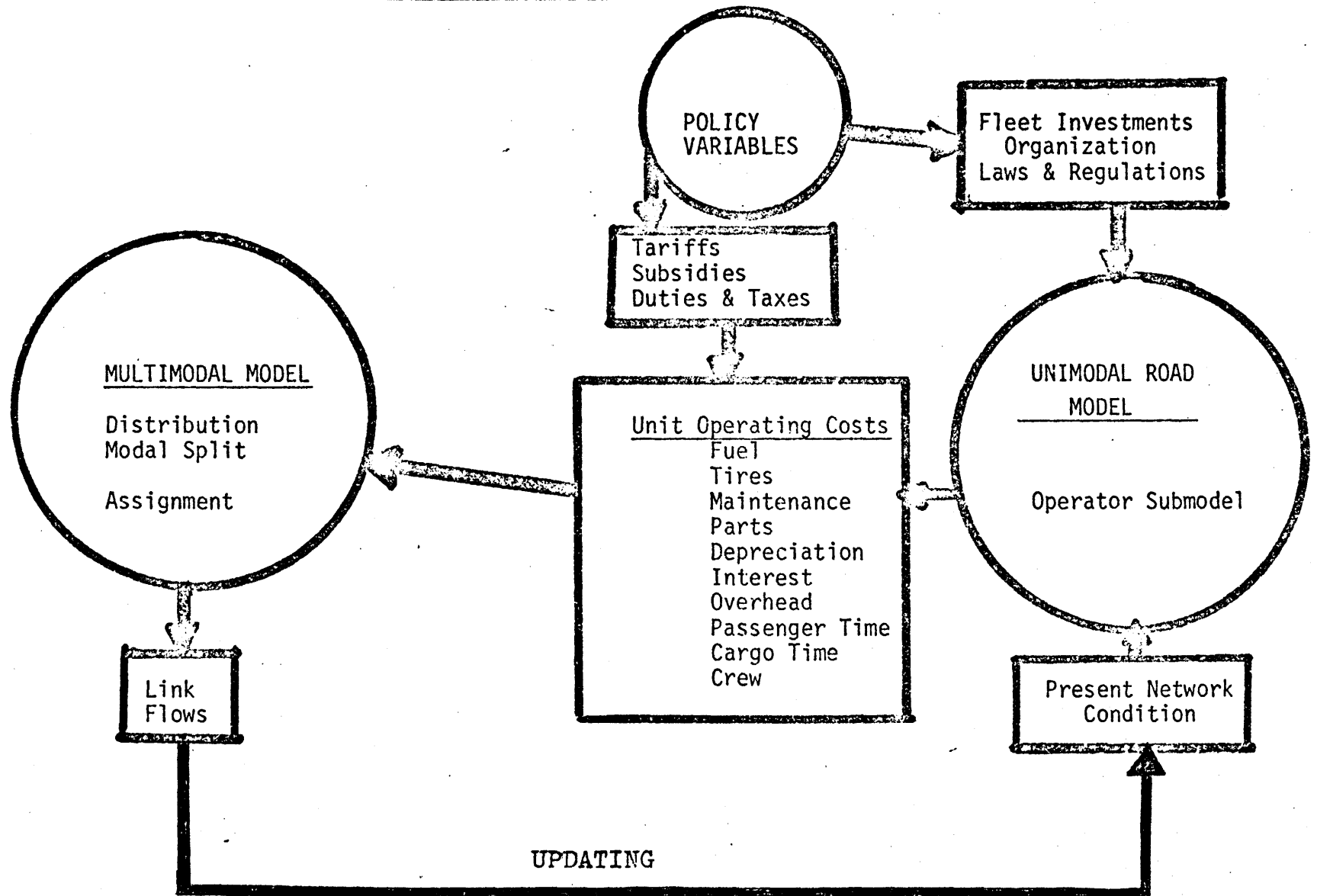
1. Unimodal environments and inputs of the models.

The major specific environments which condition the activities of transportation systems are related to four areas:

(i) Investment: Investment policy is a major determinant of the performance level of transportation systems, particularly in developing countries, where, in most cases, the provision of infrastructures will have to respond to a fast-growing demand. Besides, in many cases, fleets are old and poorly maintained, so that vehicle availability is quite low. In such a context, the investments in facility building or renewal, and in vehicle purchasing are crucial conditions of an adequate level of service. Now investments must be viewed from two angles:

- Investment cost: This involves the time framework of a long-term investment policy, and the corresponding discount rates on one hand, amortization and depreciation on the other hand, as expressed for example by the present value of any item (link or vehicle). Capital expenditures on a yearly basis are the outputs

FIGURE XI - URM → MMM DATA FLOW



of such an analysis.

- Investment impacts: they are primarily changes in physical characteristics of links or vehicles as they will be described in a following part of this chapter. These, in turn, will result in changes in the level of service and consequently in a greater attractiveness to potential users.

(ii) Organization: The organizational efficiency can be defined through a whole set of indicators ranging from various productivity rates to actual levels of operations as compared to standards. Now obviously organization will have considerable impacts upon transportation activities. A major impact is represented by maintenance policy, either of physical plants or of vehicles. Maintenance quality is a very important determinant of the level of service, through its average characteristics as well as its reliability.

(iii) Regulations: A complete list of these regulations is given in Appendix A. They are basically divided into two broad categories:

- market regulations: entry, exit, rates, rate of return;
- operating regulations: level of service, equipment, labor, environment.

Although they usually provide guidelines, they do have impacts upon operations and coverage characteristics. Service requirements are directly connected to the attractiveness of one mode. Besides most equipment,

labor and environment regulations result in additional costs.

(iv) Technology: The impact of technological features upon the level of performance is obvious. In developing countries, additional problems are connected with technology availability and subsequent foreign exchange issues, and labor force skill and the efficiency in the use of elaborate technologies. They can impose constraints upon actual technological options and therefore have an impact on the performance level of the whole transportation system, on one hand, and on the various resources consumed on the other hand. Although it is generally very difficult to describe analytically the structure of technology by a production-function in the transport sector (see Chapter III), its various components must be analyzed.

(v) Present network condition: It will be characterized by parameters related to:

- Links: First of all the very definition of links is a very important step of the whole modelling effort. Obviously it has significant impacts upon the accuracy of predicted flows. Link-parameters will first include physical characteristics such as its length, width, design speed, or capacity. Besides, both its actual level of deterioration, and its resistance to deterioration, i.e. its potential level of deterioration will have to be considered. In the case of the URM, a condition index

is defined as a function of strength value and axle-loading. In such a context, a construction project can be very simply characterized by its effects on the various parameters defined above. Besides maintenance policy, either scheduled or responsive, can be described by its impacts upon both deterioration and resistance to degradation.

- Vehicles: Each category of vehicles will have to be described by a certain amount of physical parameters such as weight, number of axles, capacity. Besides a set of fixed costs, variable ones related to resources consumption and user costs will have to be provided. At last the actual status of the fleet must be characterized through an age distribution, which can involve the notion of serviceable age, rather than actual one, as a function of actual performances, and through a vehicle availability distribution. Maintenance and investments will be mainly identified as their impacts upon the parameters and distributions defined above.

- Commodities: The first key specification is the level of aggregation which is chosen. The following attributes will have to be known for every commodity.
 - shelf life
 - value per weight-unit
 - density.

These attributes are not connected to unimodal features. On the other hand the unimodal models commodity interface will be related to environmental physical requirements for commodities, or their specific handling process; besides for each commodity, a set of feasible vehicle types will have to be provided. A corresponding constraint upon assignment will have to be taken into account, as well as specific operating costs.

Obviously the outputs of any model cannot reflect greater disaggregation and sensitivity than the inputs and internal computations. Therefore inputs are a fundamental determinant of the accuracy of the whole model. It implies a whole set of aggregation options, as well as incorporation of variables, hopefully policy sensitive. Once again, data requirements and computational ease must be two major guidelines in the choice of functional formulations.

2. Analytical tool: generalized cost function (G.C.F.)

i. Definition and general structure:

The GCF is the expression of the total unitary cost (per ton, per passenger) of a given transportation service as perceived by users for a given combination of mode, link, commodity and possibly user group.

The general structure is the following:

(I)

$$\text{COST (mode, link, commodity, user group)} = \text{USER COST} + A [\text{AVERAGE FIXED OPERATOR COST} + \text{AVERAGE VARIABLE OPERATOR COST}]$$

(II)

$$\text{USER COST} = \text{TRIP-TIME COST} + \text{UNRELIABILITY COST} + \text{LOSS AND DAMAGE COST} + \text{PRICE.}$$

Typical fixed operator costs are:

- depreciation cost
- overhead cost
- insurance cost
- administrative cost
- labor cost
- interest charges
- maintenance of way (railroad)

Typical variable costs are:

- fuel cost
- oil cost
- vehicle maintenance cost
- toll fare (highway).

The A in formula I is a "permeability constant". It is a measure of the competitiveness of a particular market, defined as a combination of mode, link, commodity and user group. It expresses the amount of the operator's total average costs which users actually pay for. On the other hand the variable "PRICE" is included in the case of a service monetary price exogenously determined by the government. When this variable is different from 0, then: $A = 0$.

The concept of permeability constant is similar to the one of "degree of monopoly" as defined by Lerner in 1934: (11)

$$D = \frac{\text{MARKET PRICE} - \text{MARGINAL COST}}{\text{MARKET PRICE}}$$

$$D = 1 - \frac{1}{\hat{A}} \quad \text{then } \hat{A} = \frac{\text{MARKET PRICE}}{\text{MARKET COST}}$$

As it is often assumed that marginal cost is equal to average cost, the practical definition of the permeability constant will be:

$$A = \frac{\text{MARKET PRICE}}{\text{AVERAGE COST}}$$

Three typical situations are to be found in the transport sector.

1. Highly competitive market: in such a case competition prevents any operator from charging much more than his actual costs, therefore:

$$A \approx 1 \text{ (or slightly more)}$$

$$\text{PRICE} = 0$$

2. Monopolistic market: in such a case the monopolistic firm can transfer to users more than the actual increase in his costs, therefore:

$$A > 1$$

$$\text{PRICE} = 0$$

3. Price regulation independently of costs: of course in such a case:

$$A = 0$$

$$\text{PRICE} \neq 0$$

Because of the equilibration procedure which will be described below, the GCF can be expressed in another way. Actually most cost components can be broken into two parts:

- a free flow part: i.e. a cost which does not depend on actual flows on the link which, for example, only depends on physical characteristics of the link or of the vehicle considered (e.g. depreciation cost; vehicle maintenance costs can be assumed to be mostly flow independent).

- a flow dependent part: this must take into account additional costs related to actual traffic and possible congestion effects on the link. Trip time for example, in most cases will obviously depend on actual flows. The relation can be analytically expressed by a volume delay curve, for example.

Consequently, the GCF can be written this way.

$$\text{COST} = \text{FREEFLOW COSTS} + \text{COST}[\text{FLOWS}]$$

The basic concern of this thesis will be to focus on free flow costs.

- ii. Interaction between investment policy, market regulations, operating regulations and the GCF.

The GCF is the main connection between policy analysis and flow prediction. The problem is to identify variables which are likely to be changed by policy decisions and then to try and quantify the magnitude of the impacts considered.

- Market regulations: The main way of dealing with them is to analyze their impact on market structure. This in turn will enter the GCF through the permeability constant A. Besides non-physical constraints to the assignment can be used, although not directly related to the GCF, as well as changes in user-specified inputs concerning commodities vehicles or links, to

deal with various types of regulations. (See Appendix A).

- Operating regulations: on one hand these will impact operator costs, through vehicle or link inputs for example. Maintenance cost as well as labor cost are likely to be changed by those regulating. On the other hand, the level of service, as represented by user costs will be changed if requirements are not met.
- Investment policy: The impact of the investment policy will be upon the physical characteristics of either links or vehicles. Consequently it will change both operator costs (maintenance operating costs...) and user cost through the performance level of the system.

As described before, these interactions will require an important modelling effort to be able to define analytical relationships between policy options and numerical changes in various components of the GCF. Obviously in many cases this analytical framework either does not exist or requires a huge set of simplifying assumptions, likely to induce important errors in computations. One must remain aware of the inherent limitations of mathematical modelling. Therefore the very structure of the unimodal models must be very flexible and allow a constant interaction with the user, avoiding the danger of a "black box", the internal computations of which cannot be controlled at all.

iii. Role in the equilibration procedure.

The traditional procedure of transportation planning was sequential

and involved four steps and submodels:

- trip generation
- trip distribution
- modal split
- traffic assignment.

The internal consistency of the whole framework has proved to be very questionable, particularly between trip distribution and traffic assignment. Besides no iterative way of solving the problem has any reliable convergence property. Consequently there must be a simultaneous equilibration procedure. A converging one has been proved to be possibly treated as a mathematical programming problem. (See Terry L. Friesz and J. E. Fernandez-Larranaga. Design of a multimodal, intercity transportation planning model: the equilibration methodology.(12))

The objective function is the sum of a monotonic transformation of the system entropy and a particular transformation of individual costs, as expressed by the GCF, more specifically:

$$\sum_{\substack{\text{mode, link,} \\ \text{commodity}}} \int_0^{U_{m,1,c}} C[U] dU$$

$U_{m,1,c}$: flow of commodity c , by mode m , on link l . The set of flows $U_{m,1,c}$ is the simultaneous solution of trip distribution, modal split and traffic assignment.

The second component of the objective function expresses the very widely used user optimization assignment, formulated by Wardrop.*

Then we see that generalized cost-functions play a very central part within the equilibration procedure. Consequently their accuracy conditions the very efficiency of the whole model.

3. Further internal computations and major outputs.

In addition to the simulation of operations leading to the actual determination of the generalized cost function, a whole set of additional computations have to be made within unimodal models. Their purpose is to determine the impacts of actual flows on the network upon users, operators and owners. They form the second set of outputs of unimodal models as described by Figure X.

These outputs are mainly related to three areas:

(i) Level of service: It is a key element of the attractiveness of a mode. It can be summarized by a set of attributes on which actual flows have impacts. These attributes are:

- Origin-destination trip-times (average data): The main effect involved is congestion. A link is said to be congested when trip-time is a function of volume, usually asymptotically increasing to infinity, when volume approaches link-capacity. The

*i.e.: a user-equilibrium is one in which no individual can improve his situation by a unilateral change of route.

functional representation is a volume-delay curve. The observation of actual data usually allows to calibrate such a curve. A detailed congestion analysis can be made if one suspects such effects, which mainly concern highway transportations and terminal operations for railroad and inland waterway transportations (yards, stations, locks).

- Reliability: The connection between flows and reliability, although intuitively straight-forward is very difficult to handle in an analytical way, partly because it has to deal with distributions, and consequently raises data collection problems.
- Loss and damage: The impact of flows upon loss and damage are undoubtedly significant. A modelling framework, based on regression analysis, will be described in a following chapter.

All level of service attributes implicitly or explicitly include flow-dependent terms. Computational ease can lead to neglect of those terms in a first assignment, and proceed through a partly iterative approach if the effects involved are significant. This remark also applies to certain unit costs (vehicle maintenance for example).

(ii) Physical status of the system: deterioration, maintenance and investment. This is a crucial output of unimodal models. The impact

of flows upon the physical status of the link can be summarized in two ways:

- The present deterioration level, which can be summarized by a wide range of physical parameters (roughness, soil consolidation, loaded draft, canal bank deterioration). It will, in turn, have impacts upon the level of service and upon required maintenance works, either periodic or responsive, in terms of man-hours, materials and parts. As regards vehicles, both serviceable age distribution and vehicle availability are impacted by conditions of utilization. Maintenance policy is, here again, directly involved.
- The resistance to deterioration of the facility considered. This strength value is the analytical link between flows and actual deterioration. For example the speed of sedimentation in canals, or bank stabilization can be improved.

We see that there is some kind of a loop relationship. Investment and maintenance policies condition the level of service, which determines flows, which in turn imply investments and maintenance works to meet deterioration and demand requirements. Both maintenance and investment will result in costs, both financial and economic. They will be the basis of the updating of modal environments and inputs as described in Figure X.

(iii) Accounting analysis. The last output of unimodal models is a complete accounting analysis of the transportation system. The major areas of this study will be:

- capital expenditures: construction costs will be summarized for the period considered.
- costs: maintenance costs and operating costs, in financial and economic terms will be described (for both physical plant and fleet).
- revenues
- profits or losses: they will be given obviously as the difference between the two items above.

A consequence of this computation will be the evaluation of the need for subsidies for non-profitable transportation activities; an alternative way of dealing with this problem is a tariff-adjustment.

- At last the depreciation procedure will allow to compute a present value for the network.

A sample of outputs, in the format considered for the URM, are given on Figure XII and XIII.

Figure XII
FINANCIAL COST SUMMARY
(Million Egyptian Pounds)

YEAR	LINK CONSTRUCTION COSTS	LINK MAINTENANCE COSTS	USER COSTS	GROSS REVENUES	FLEET OPERATION COSTS	FLEET MAINT. COSTS	Alternative Traffic Economic Scenario	
							FLEET INVEST. COSTS	TOTAL TRANSPORT COSTS
19xx								
TOTALS								

SALVAGE
VALUES

(1)

(2)

DISCOUNTED
at

%

%

%

%

%

(1) Total link value in final year

(2) Total fleet value in final year

Figure XIII
ECONOMIC COST SUMMARY
(Million Egyptian Pounds)

Alternative _____
Traffic _____
Economic Scenario _____

<u>YEAR</u>	<u>LINK CONSTR. COSTS</u>	<u>LINK MAINT. COSTS</u>	<u>FLEET OPERATION COSTS</u>	<u>FLEET MAINT. COSTS</u>	<u>FLEET INVEST. COSTS</u>	<u>TOTAL TRANSPORT COSTS</u>	<u>TOTAL FOREIGN EX- CHANGE COSTS</u>
-------------	-----------------------------------	----------------------------------	--------------------------------------	-----------------------------------	------------------------------------	--------------------------------------	-----------------------------------------------

19xx

}

TOTALS

SALVAGE
VALUES

(1)

(2)

DISCOUNTED
AT

_____%
_____%
_____%
_____%
_____%

(1) Total link value in final year

(2) Total fleet value in final year

CHAPTER III

TRANSPORTATION COST FUNCTIONS

Introduction: the two basic approaches.

A literature review showed that there are two main approaches to transportation cost functions from the operator's point of view:

i. an econometric approach, based on economic theory, which can be summarized this way. The transportation system is characterized by a cost minimization behavior, given a level of production, represented by a production function. The solution of a mathematical program provides a cost function, either short-term, where capital is considered as fixed or long term when it is an optimization variable. The functional result is then estimated through econometric methods.

ii. an engineering approach, which focuses on technical operations. Then deriving unit costs and assuming that they are constant in a relatively small range of technology options and levels of output, this approach allows to calculate estimates of costs in various conditions of investment, organization, regulation and technology.

The following section will be a literature review related to these two approaches and through it, a description of their main features.

N.B.: a particular focus will on railroads as regards specific examples.

I. Economic theory and econometric approach.

Relationship between production function and cost function.

The basic assumption involved in the theory of production and cost is that firms are cost-minimizers at a given level of output. Therefore the basic theoretical framework is the solution of a mathematical program of the following form:

$$\begin{aligned} \text{Minimize } & \sum_j Y_j w_j \\ \text{s.t. } & P(\{X_i\}_i, \{Y_j\}_j) = 0 \end{aligned}$$

where: X_i = outputs

Y_j = inputs

$P(\{X_i\}_i, \{Y_j\}_j)$ = production function

w_j = cost of input j

$C = \sum_j Y_j w_j$ = cost of inputs

If the input "capital" is held constant, then the solution of this mathematical program is the short-run cost function. If all inputs (energy, labor, capital...) are variable, then the solution is the long-run cost function.

Duality theory implies that the long-run cost function describes a well-behaved technology as well as a production function, provided certain mathematical properties. Therefore, in theory, provided that cost-minimization holds, the mere data of short-run cost functions at various

levels of capital allow to deduce the long-run cost function, as their envelope, and consequently the structure of technology.

Then within this framework, if the purpose is to derive cost-functions, either short-term or long-term, we need:

- a functional expression of the production function
- prices of inputs.

Reversely, cost-functions allow to go back to the structure of technology.

Now the validity of econometric estimates derived from the framework described above is highly questionable. According to Ann Friedlaender there are three major reasons to this phenomenon: (13)

1. The output of transportation firms is multidimensional. Transportation services have very different characteristics within the same firm: different users, origins, destinations, quality of service. The mix of outputs can have a major impact upon costs of any given firm. Consequently, an aggregate measure of output is not adequate. The quality of services must be incorporated. There is a tradeoff at this point between data requirements and theoretical relevance.
2. Because of joint and common costs, transportation industry is characterized by joint production. Therefore a separable Clobb Douglas production function, which is the most widely used in the literature is not necessarily a good representation of reality.

3. Because of a heavy regulatory environment, firms are generally not in a position of long-run equilibrium, operating along their long-run cost function. Consequently efforts to estimate directly long-run cost function from cross-sectional data will obviously yield wrong results. Generally the subsequent bias will depend on the firm size and the degree of excess capacity which is generally not known. This problem is particularly acute in the railroad sector.

Consequently the theoretical economic approach of costs should include:

- a multiple output cost function
- sufficient flexibility to test different hypothesis about separability, homogeneity and jointness of the underlying production function.
- the estimation of short-run cost functions, each time a long-run disequilibrium is suspected in the firm. The actual long-range function will be deduced as the envelope of the former ones. If short-run coefficients are unbiased, long-run ones will be too.

The basic theoretical framework used in the literature is generally the same. Differences occur only in the estimation techniques which raise many problems such as aggregation, proper expressions of outputs, choice of adequate prices of inputs, consideration of the firm size.

The standard form of the mathematical program uses a Cobb-Douglas production function:

$$\text{Minimize } C = w_L L + w_E E + w_K K$$

$$\text{s.t. } Q = A L^{\beta_1} E^{\beta_2} K^{\beta_3}$$

where: L = labor

E = energy

K = capital

Using Lagrange method:

$$\ell = C - \lambda [Q - A L^{\beta_1} E^{\beta_2} K^{\beta_3}]$$

$$\text{then: } \frac{\partial \ell}{\partial L} = w_L + \lambda \beta_1 \frac{Q}{L} = 0$$

$$\frac{\partial \ell}{\partial E} = w_E + \lambda \beta_2 \frac{Q}{E} = 0$$

then solving in L and E :

$$L = \left(\frac{Q}{A K^{\beta_3}} \left[\frac{w_E \beta_1}{w_L \beta_2} \right]^{\beta_2} \right)^{\frac{1}{\beta_1 + \beta_2}}$$

$$E = \left(\frac{Q}{A K^{\beta_3}} \left[\frac{w_L \beta_2}{w_E \beta_1} \right]^{\beta_1} \right)^{\frac{1}{\beta_1 + \beta_2}}$$

$$\text{then } C = w_K K + w_E E + w_L L$$

$$\text{if } \beta = \beta_1 + \beta_2$$

$$C = w_K K + Q \frac{1}{\beta} A \frac{-1}{\beta} K \frac{-\beta_3}{\beta} w_E \frac{\beta_2}{\beta} w_L \frac{\beta_1}{\beta} \left[\left(\frac{\beta_1}{\beta_2} \right)^{\frac{\beta_2}{\beta}} + \left(\frac{\beta_2}{\beta_1} \right)^{\frac{\beta_1}{\beta}} \right]$$

The next step is the estimation of this equation, which usually raises many problems. A long-term cost function can be derived for example by allowing K to be variable and optimizing C according to K.

An alternative approach has been attempted by A. Friedlaender, to try to meet the three characteristics mentioned above. The translog function approximation is used for short-run cost functions and estimated. Afterwards a long-run cost function is derived and then a production function using a dual approach. The fact of using second order approximations of these actual functions allows a great flexibility in their definition, and to calculate gradient and Hessian values at the point of expansion. Then the translog approximation of the production function being but a function of those values, can be derived. A broad spectrum of sophisticated and quite costly estimation procedures leads to the obtention of functions which are but approximations, although they might be very close to reality. There is definitely a tradeoff. These two approaches clearly show that theoretical goodness and practical results are hardly compatible. Either you have to make highly questionable theoretical or functional assumptions and you get results with a poor degree of accuracy; or you try and respect theory requirements and you

obtain approximated results of the supposedly proper functions. (13)

Specific references used in this section.

Borts, G.H. (1960): The estimation of rail cost functions.

Griliches, Z. (1972): Cost allocation in railroad regulation.

Keeler, T.E. (1974): Railroad costs, returns to scale and excess capacity.

Pozdena and Merewitz (1977); Estimating cost functions for rail rapid transit properties.

Friedlaender and Spady (1976): Econometric estimation of cost functions in the transportation industries.

Kneafsey, J.T. (1975): Costing in railroad operations: A proposed methodology.*

II. Engineering cost functions.

The second basic approach is what one might call engineering cost-functions. There is no economic theory involved in it, as well as no important behavioral assumption about the firms considered. The basic consideration on which these cost functions rely is that, within a certain range of the main physical units involved (either inputs or outputs) total costs can be derived from constant unit costs. Consequently, the determination of a set of basic unit costs allows to calculate total costs, provided there is no dramatic change in the underlying structure of technology or economics of the industry considered.

There are several ways of obtaining relevant unit costs:

*See references.

- mere observation of operations: Thanks to historical data, it is possible to compute unit-costs and to extrapolate from them when considering the operations during the following time period. One has but to know the total costs of various operations and the number of physical units involved in them.
- regression relationships: In several cases, there can be implicit relationships between unit costs and other variables used within the model. In such a case it can be interesting to make these relationships explicit. Regression is a useful tool to provide simple analytical equations. For example, fuel consumption unit cost can be related to physical characteristics of the link and vehicle considered.
- analytical modelling: In fact regression is the simplest analytical model and therefore a particular case of this approach. It is used, each time a clear and relevant analytical formulation is not found. This method can be used for example in dealing with rolling-stock requirements, using queueing theory and probability distributions, or again in fuel consumption, using engineering formulas. The basic framework is then simulation of operations on the link considered: from operational data such as car-miles, ton-mile, cars, mileage, total costs can be derived from unit costs.

A whole set of such an approach of transportation cost functions can be found in the literature. A sample will be given below. It is neither an exhaustive list, nor the state of the art in the field, but

each example has some special features likely to be used in this research.

ROAD INVESTMENT ANALYSIS MODEL: (10)

The purpose of this model is to evaluate link alternatives in terms of costs, both for the operator and for users. Various combinations of link investments and maintenance policies can be tested and compared. The basic simulation framework is summarized on Figure XIV. A whole set of submodels describes the impacts of the alternative considered and the subsequent traffic flow assigned on the link on maintenance and deterioration on one hand, on vehicle operating costs on the other hand. Engineering formulae relate these impacts to the physical characteristics of both the link considered and the vehicle involved. This model combines the three approaches described before. A great focus is on system deterioration, which is modelled at a very detailed level. Anyway highway transportations are probably the only ones that can be modelled with such an accuracy because of an important data basis and of the great focus they have benefited from in recent years both in developing and developed countries.

HARVARD-BROOKINGS MODEL: (3)

The general structure of this model has been described before. As regards specific cost-performance models, the basic simulation frameworks can be seen on Figure XV and XVI, concerning highway and railroads. Cost

FIGURE XIV

DATA REQUIREMENTS

National or Regional Parameters

Design Standards
 Geometric standards
 Pavement sections
 Material characteristics

Maintenance Standards
 Routine Maintenance Criteria
 for Earth Gravel and
 Paved Roads
 Resurfacing Criteria

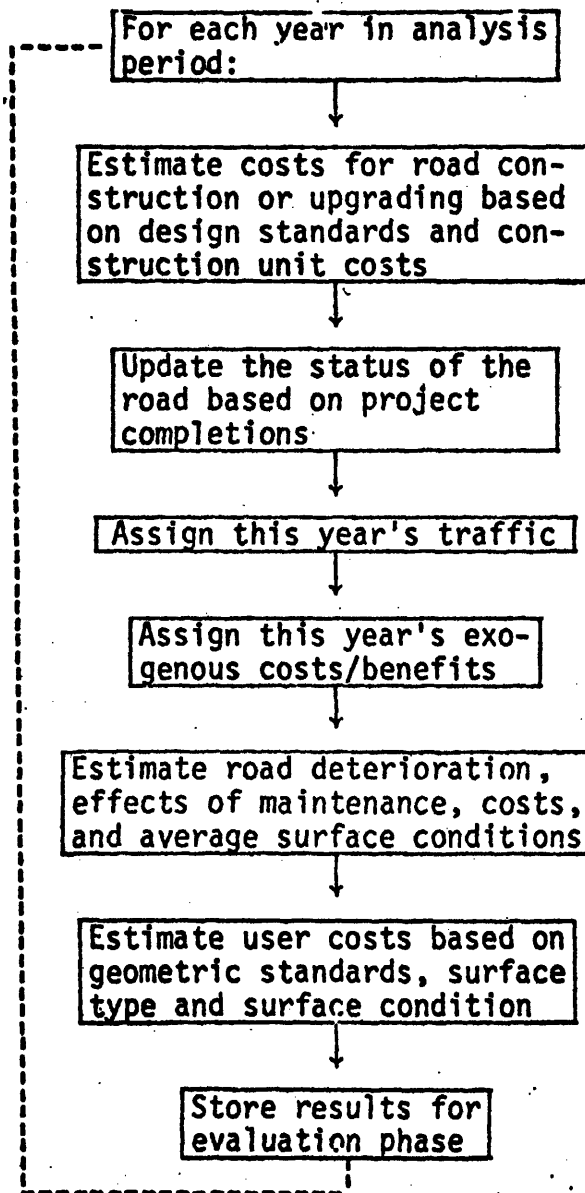
Highway Program Parameters

Construction Unit Costs
 Maintenance Unit Costs
 Basic Vehicle Ownership
 and Operating Costs

Project Parameters

Traffic
 Exogenous Costs/Benefits
 Physical Characteristics of
 the Alignment
 Specific Design and Maintenance
 Standards to be Studied
 Schedule for Implementation

SIMULATION OF A LINK-ALTERNATIVE



RESULTS

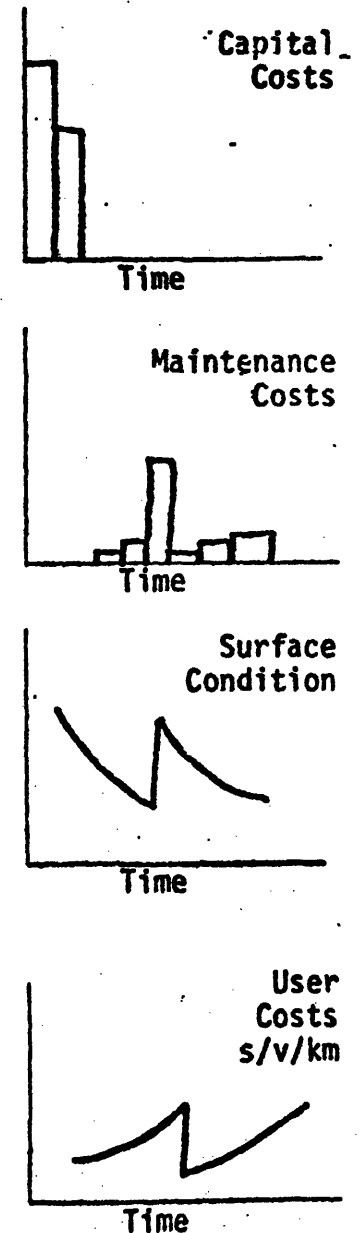


FIGURE XV

Steps in Using the Highway Cost-Performance Model

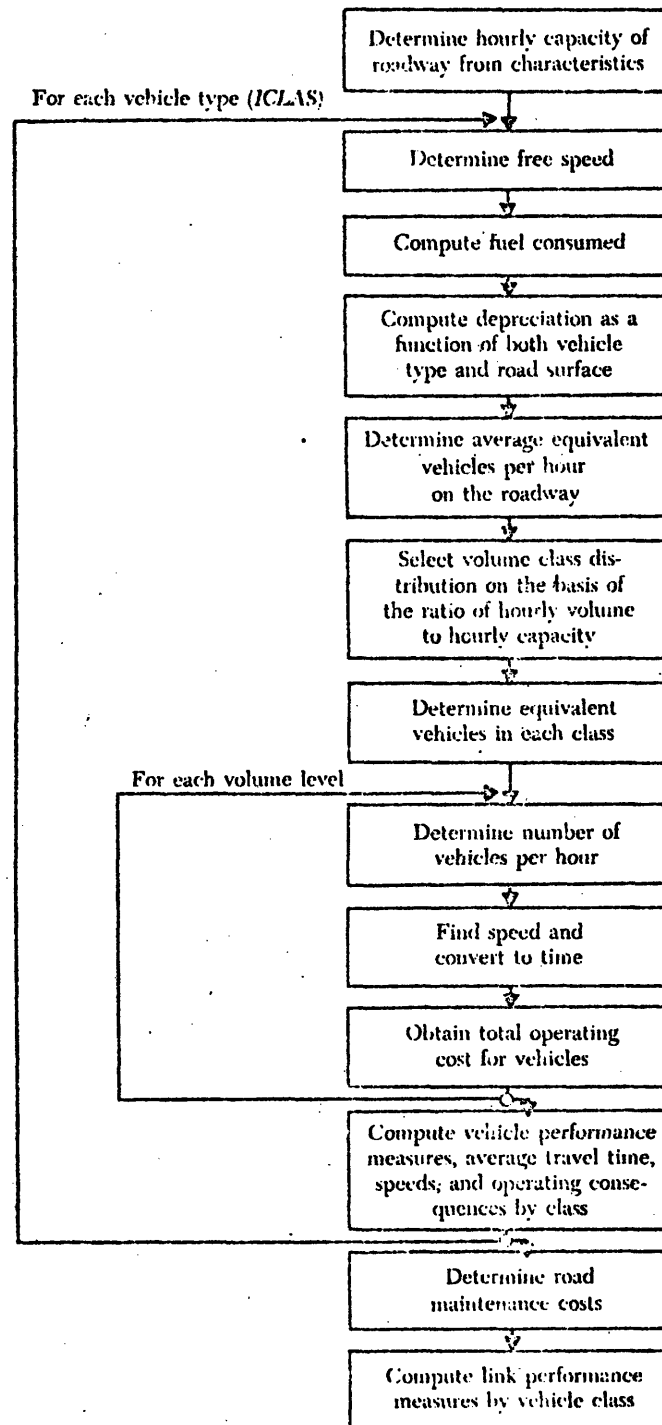
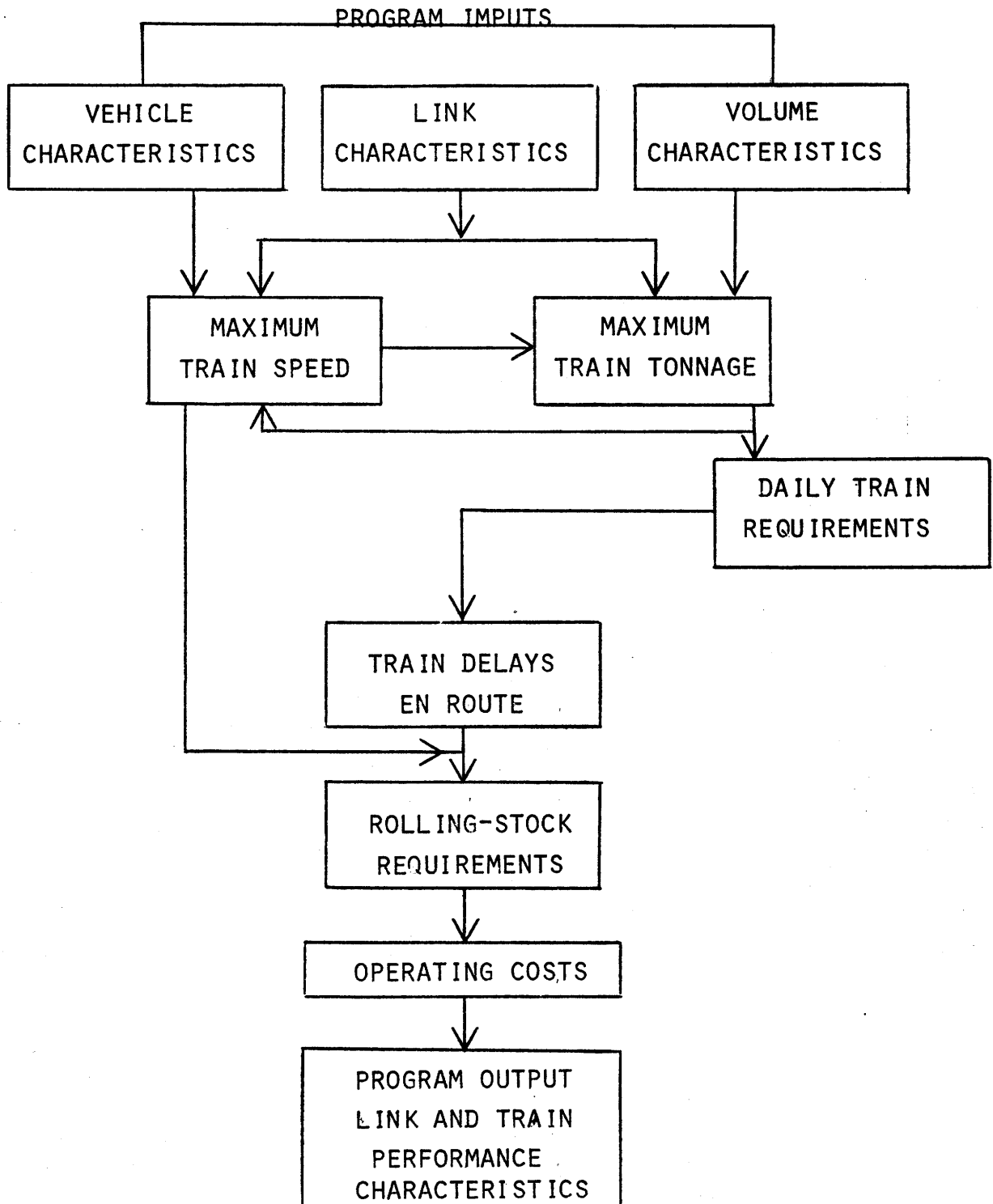


FIGURE XVI
SIMULATION RAILWAY MODEL
(HARVARD BROOKINGS)



calculations involve either engineering formulae or very straightforward analytical forms. The model was totally deterministic. In the cases where obviously it had to deal with stochastic processes, it only took into account average values, which, of course, makes computations and data requirements much lighter but results in an important loss of accuracy, particularly as regards modes, such as railroads, where reliability is a key-factor, particularly in developing countries. Besides a general criticism which has been done was that many costs were too much aggregated. The influence of their various implicit components would have been interesting to evaluate. Causal relationships were to some extent hidden by those very simple formulae.

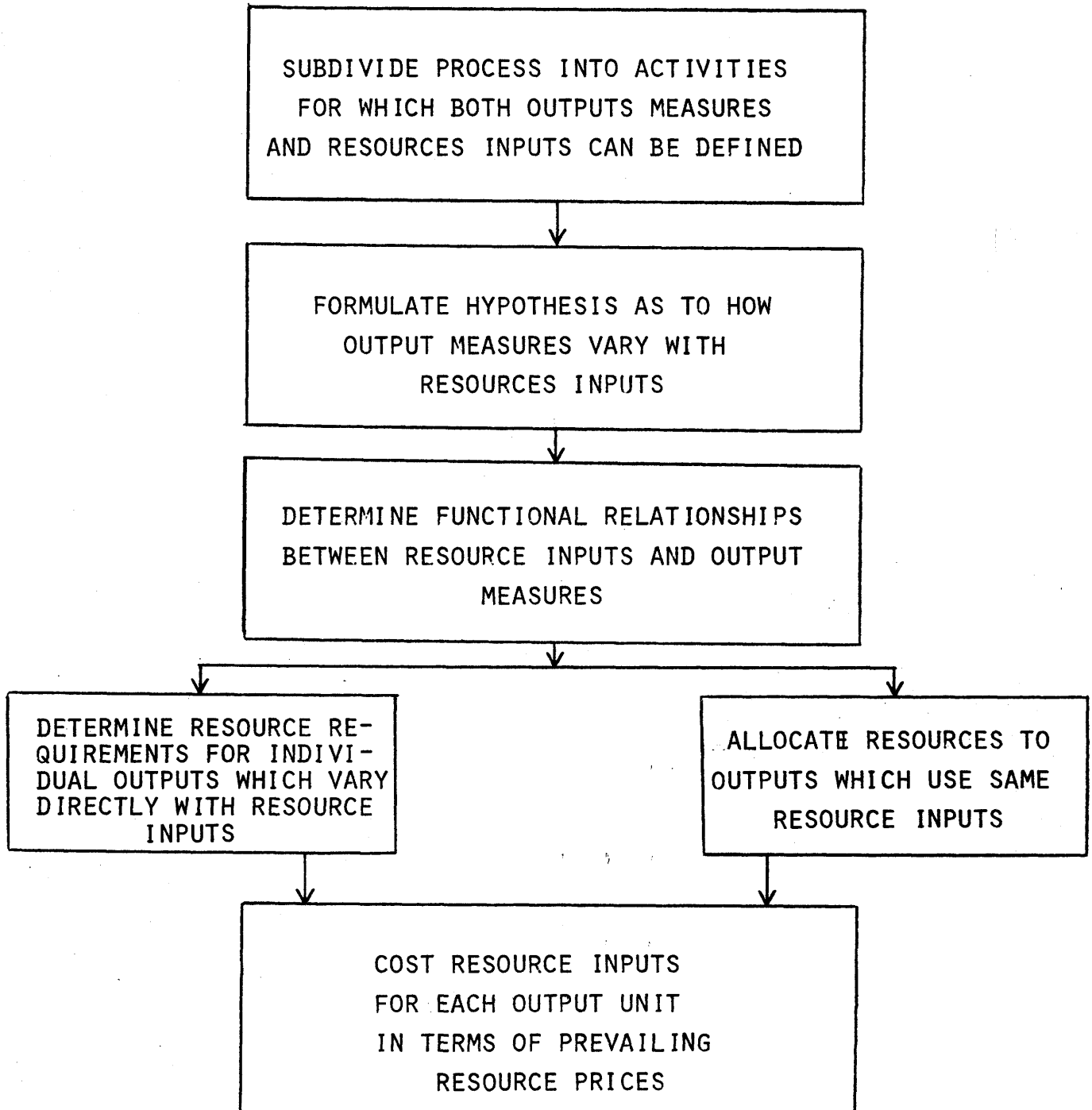
AN ECONOMETRIC ANALYSIS OF MOTOR CARRIER LTL TRANSPORTATION SERVICES:

A.D. SCHUSTER (Ph.D Thesis: 1977). (14)

This example is mentioned because it is an interesting application of regression to costing in the trucking industry. The main purpose of the study was to analyze the relationship between shipment characteristics and subsequent operating procedures and costs. The methodology used was the so-called statistical cost approach, which is summarized on Figure XVII. The analysis was a micro-scale level, the lowest level at which output measures and inputs of resources could be defined. Consequently the simulation of operations was very detailed and implied huge data requirements. Besides statistical results seemed to be rather loose. Still this approach is interesting since it is an extreme case of on one hand analyzing very thoroughly transportation operations, and on the

FIGURE XVII

STEPS OF THE STATISTICAL COST APPROACH



the other hand using systematical regression to represent causal relationships in a very straightforward way. Beside the methodology described in Figure XVII is a very good description of the general framework of engineering cost-functions. The main differences can occur in the level of detail of the first step, and in the nature of the functional relationships of the third step. They are certainly the two main options.

P.O. ROBERTS ET AL: CORRIDOR STUDIES.

The whole set of these studies is given in section I.3. The basic framework is described in "a set of simplified multimodel cost models for use in freight studies." (15)

The basic formula used is the following:

$$C = F + [V \times \text{DIST}] + \text{PUD}$$

Where: C = cost, F = fixed cost/unit, V = variable cost/unit-mile,
PUD = pick-up and delivery charge (additional)

Furthermore:

- F = handling + general and administrative
- handling = pick-up and delivery + terminal handling + billing
- general administrative = PUD equipment ownership + infrastructure ownership + management
- V = variable cost/unit mile = linehaul + vehicle ownership

- linehaul = crew + fuel + maintenance
- vehicle ownership = power units + load units.

The same formulation can be used for short-run costs, if ownership costs are dropped for example.

The next step is the determination of each component as shown in Figure XVIII. In this case the approach is clearly the observation of data related to operations. There is no analytical modelling involved in this very application. But in other cases, sub-models can very well be incorporated to the whole cost model. For example, in "TOFC versus COFC: a comparison of technology" (9), a fuel consumption model was used to compute fuel costs.

This very broad formulation allows great freedom on the level of detail, as well as the degree of modelling effort involved in the study.

III. Choice of the engineering approach.

The main shortcomings of the economic approach of transportation cost functions have been pointed before. They are basically:

- behavioral: cost minimization is definitely a handy theoretical framework in economic theory. The fact that many transportation firms, mainly because of regulation are not on their long-run curves, and difficulties in accurately determining a proper

FIGURE XVIII

1974 TRUCKING UNIT COSTS FOR USE IN THE DEVELOPMENT OF COST FORMULAS

	Private Shipper Owned		Contract and Irregular Route		Regular Route Common Carrier					
					TL	TL	TL	LTL	LTL	LTL
	1-40	2-40	1-40	2-27	1-40	2-40	2-27	1-40	2-40	2-27
Variable Cost/vehicle mi.=Linehaul + Ownership										
Linehaul										
1) driver			.190		.190	.190	.330	.330	.330	.330
2) fuel			.067		.097	.067	.068	.067	.068	.068
3) tires			.018		.034	.018	.018	.034	.018	.018
4) taxes			.027		.039	.027	.027	.039	.027	.027
5) supervision			.016		.016	.016	.016	.016	.016	.016
6) insurance			.036		.072	.036	.054	.072	.036	.054
7) tractor maintenance			.045		.045	.045	.045	.045	.045	.045
8) trailer maintenance			.020		.040	.020	.040	.040	.020	.040
subtotal			.419		.533	.419	.448	.559	.673	.588
Ownership										
9) tractor capital recovery			.065		.087	.043	.043	.065	.087	.065
trailer capital recovery			.020		.046	.020	.035	.020	.046	.035
subtotal			.085		.133	.063	.078	.085	.133	.100
Total Variable Cost/veh. mi.	.504		.504		.666	.482	.516	.644	.688	.688
Fixed Cost/ton⁴ = Handling + General and Administrative										
Handling										
11) Pickup and Delivery			1.85		1.85	1.85	1.85	3.70	3.70	12.22
12) Terminal Delivery			0		0	0	0	0	8.27	8.27
13) Billing			.10		.10	.19	.19	.19	.96	.96
SUBTOTAL			1.95		1.95	2.04	2.04	3.89	3.89	21.45
General and Administrative										
14) Terminal Ownership			.02		.02	.02	.10	.10	.10	.10
15) Management			1.00		1.00	2.25	2.25	2.25	2.25	2.25
subtotal			1.02		1.02	2.27	2.35	2.35	2.35	2.35
Total Fixed Cost/ton	2.97		2.97⁶		4.31	6.24	6.24⁶	6.24	23.80	23.80
									23.80	22.53

Source: Based on David A. Knapton and Ralph B. Tucker "The Prospects for Rail-Truck Intermodal Systems", DOT/TSC Draft Report No. S.S. 212-UL-34, December, 1976, p. A-2, Revised with respect to tractor and trailer capital recovery and fixed costs.

¹ Basic assumptions are trailer price = \$7200, life = 10 yrs., salvage value = 0%, interest = 6%, use = 5000 mi./yr., tractor price = \$30,000, life = 5 yrs., salvage value = 20%, interest = 8%, use = 100,000 mi./yr. CRF for 6%, 10 yrs. = .13587. CRF for 8%, 5 yrs. = .25046.

² Use = 150,000 mi./yr.

³ Tractor price = \$40,000.

⁴ LTL based generally on Knapton-Tucker costs per trip @15 tons/truck.

⁵ Assumed less handling on comparative effort because of greater ability to load direct.

⁶ Note that trailer drayage for 2nd trailer has not yet been added.

production function are major stumbling blocks.

- statistical: The aggregation level in inputs as well as in outputs has to be very high within this framework. Consequently practical operating options for example are very difficult to handle as well as more global transportation policy options. The level of service is very schematically described.

On the other hand, although the engineering approach is much less satisfactory from a conceptual point of view and its range of application is limited per se (because of the assumption of constant unit costs) it has the major advantage of being very flexible. Its level of detail can vary dramatically and the connection between physical operations and their monetary costs is explicit. Yet its ability to reflect, for example, market structure is much more questionable. A way of dealing with this has been described above.

Therefore, given the ultimate purpose of such a model, which is to test policy-options, many of them being operating procedures, engineering cost-functions seem to be more adequate. A periodic updating of unit costs and a careful monitoring of changes in technology should overcome the inconveniences of having to assume constant unit costs.

IV. User's costs.

The second component of the GCF is a set of user costs. They are:

- trip-time: the time considered is the overall trip-time, including all delays, since obviously this is the criterion which is used by the shipper in his modal choice; the two basic components of trip-time are:

- mean
- variance.

Mean is what is considered as the level of service attribute "trip-time". The whole distribution of trip-time must be known, to determine these two major parameters. A model can be used, hopefully reflecting the operating options of the carrier considered.

- reliability: Many variables can be used as processes of reliability, such as:
 - standard deviation or variance: a reproach that can be done is the too great importance of extreme points of the distribution, where observed data are involved.
 - N days %: Maximum percentage of vehicles arriving within an interval of N days.
 - % late: percentage of vehicles arriving N days after the mean or the median of the distribution. This variable seems particularly adequate, when dealing with inventory problems which are the major area of influence of reliability.

A few other indicators of the way the distribution is spread around its mean can be used.

- loss and damage: This level of service attribute can either be expressed by the probability or percentage of loss and damage or its absolute level, according to the mode, commodity, and flows. Either extrapolation or a regression model can be used to predict these figures.
- prices: This variable is simply the charge upon users, when fixed exogenously by regulating authorities. Models of freight tariffs may be useful both for analysis of tariff structure and for the generation of tariff rate estimates. Explanatory variables are usually: weight, density, value, physical state, specific requirements (temperature, shock protection, special handling). The best type of regression model used in the literature seems to be a product form.

To each of the three first components of the user's cost corresponds a unit cost, to produce a monetary value. Let us review these dollar values and possible ways of modelling them, based on their actual economic or managerial meanings.

- Time cost: The dollar value associated is known as the value of time. Empirical stratified statistical estimates allow to relate value of time to socio-economic variables such as income (for passengers), or to the shipper's attributes (for freight). Although there is no general agreement about definition as well as estimation, correct estimates are obtainable (as confirmed by comparison between actual modal split and predicted one).

- Trip-reliability: the impact of reliability upon users is twofold:

- through a safety stock cost which is deterministic
- through a stock-out cost which is stochastic.

They result from the complex interactions between the level of service attributes, the receiver's attributes, the market attributes and inventory decisions.

This basic paradigm can be summarized by the diagram shown on Figure XIX.

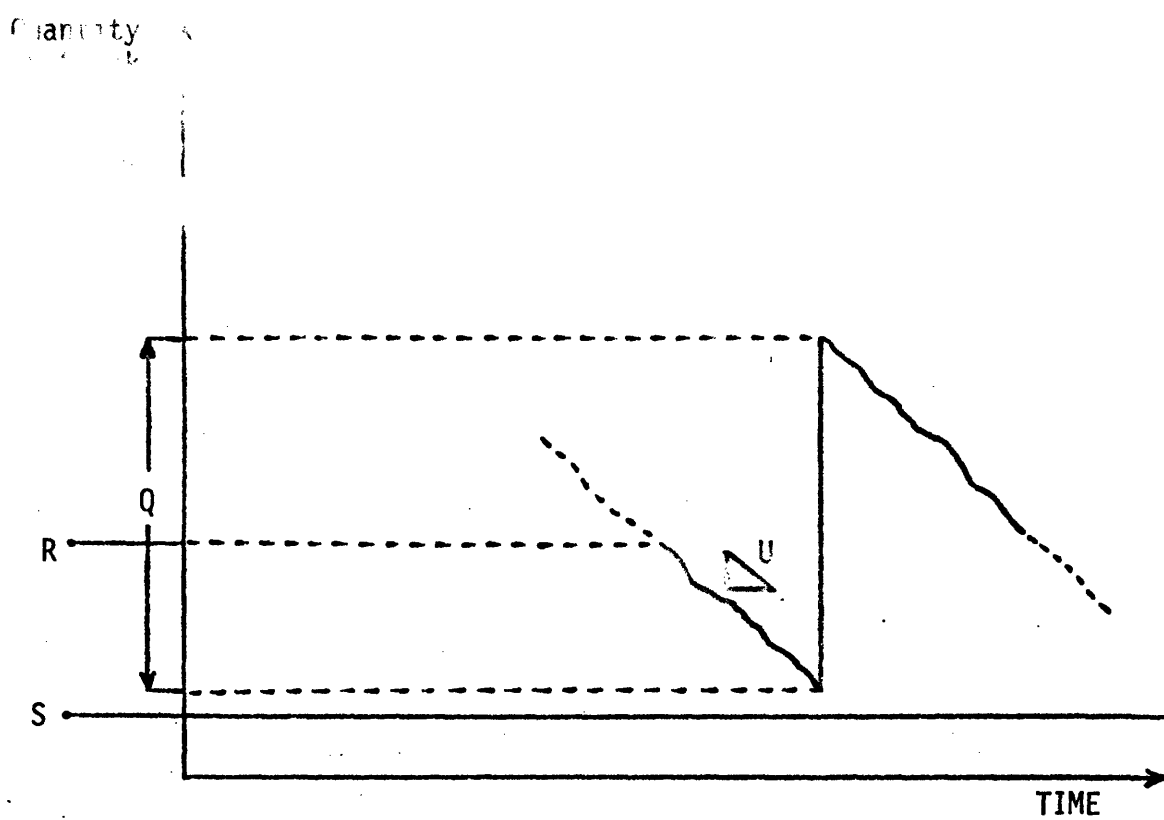
The main stochastic determinants of the process are:

- the trip-time distribution, as expressed by the lead time L , i.e. the time between the order point and the actual arrival of the goods ordered.
- the use-rate per unit of time U which describes the demand for the goods considered and determines the pattern of decrease of the quantity on hand.

They should be described by their probability distributions. In this context the logistics decision-making process can be summarized this way: determine the reorder point R , the amount reordered Q , so that the probability of being out of stock when the goods arrive is inferior to a policy threshold value, fixed a priori.

The safety stock can be expressed as:

$$S = R - E[L] \times E[U]$$



R = reorder point (amount of items on hand when the order is set up).

$E[L]$ = expected lead time

$E[U]$ = expected use rate.

The underlying idea is that on the average, the amount on hand should not be below this safety level.

There are two main inventory control techniques:

- fixed reorder point: each time the quantity on hand falls below a given level, R , an order is set-up. We see that in this case the safety stock is likely to be used during the lead time L .
- fixed reorder period: in this case, at constant intervals of time, a variable order is set up. In such a case the safety stock must cover a time which is the sum of the period and of the lead-time.

Several models have been designed to optimize the various decision-variables involved in the process.

The first cost component is then the capital carrying cost of the safety stock, i.e.:

$$\boxed{S \times i} \quad \text{or} \quad \boxed{\int i S(t) \frac{dt}{365}}$$

(fixed safety stock) (variable safety stock)

i = interest rate

The second one is the expected stock-out cost. There is definitely a problem in evaluating it. There are two relevant factors:

- the duration of stock-out
- the number of items missing.

According to the firm considered (production, wholesale, retail) penalties related to stock-out can range from the mere contribution of the unsold product, to the cost of stopping the production process because of a lack of input.

Therefore the adequate measure of stock-out can be:

- the expected duration
- the expected level of stock-out
- the expected number of item-days of stock-out
- the probability that any stock-out occurs.

Actual numerical approaches can be found in the literature, but usually they are based on very strong assumptions because of the complexity of the problem and the huge amount of data its exact solution would require.

Observed data, differentiated according to shippers are probably the only way of dealing with stock-out costs. But, from a theoretical point of view, the provision of all the data of Figure XIX, including the probability distributions of U and L , and the type of the firm involved,

would allow to calculate exact unreliability costs.

Specific References:

B.L. Kullman: A model of rail-truck competition in the inter-city freight market.

P.O. Roberts: Factors influencing the demand for good movements.

P.O. Roberts et al: development of a policy sensitive model for forecasting freight demand.*

Loss and Damage

Considering the U.S. case, loss and damage represent a sizeable drain on commerce, imposing additional costs both on shippers and on carriers. Total costs of loss and damage have been estimated to 13 billion dollars per year. Therefore it is definitely an important attribute of transportation modes. The main reasons for loss and damage are:

- mechanical failure: e.g. temperature control, breakdowns resulting in longer travel-time for perishable goods.
- human errors: improper handling by the carrier, misrouting...
- theft and pilferage: this can be very important in developing countries.

According to the regulatory framework, loss and damage can be borne in different proportions by the shipper and the carrier. Therefore the user's cost can vary, according to the shipper's liability. In any case loss and damage costs have two major components.

*See references (16), (17), (6).

- Losses not made-up by claims payments. This is the fraction of lost goods which is not reimbursed by the carrier at fault. It can vary dramatically according to the legal environment in which the transportation service has been provided.
- Cost of capital tied up in claim processing: this cost is related to the length required for claim processing and to the rental rate of capital. Besides shipper's costs include administrative expenditures, possible insurance costs, loss of market value, contractual penalties for non-delivery...

If direct costs seem to be easily modelable (first category above), indirect ones are somehow difficult to apprehend, all the more so as data can be difficult to obtain. But there is no evidence that indirect costs are dramatically different according to modes. Therefore, since modal split and traffic assignment are the ultimate purposes of the evaluation of user costs, it may not be such a stumbling block. Differential costs are the main element of modal split. Another problem is the impact of loss and damage on the inventory process, described before. This is hardly modelable. It can be sensibly assumed that if loss and damage are, on the average, significant, shippers take them into account when determining their inventory policy.

As a conclusion, direct costs of loss and damage, i.e. the value of lost goods which is not reimbursed by carriers are probably the major element to consider. A model of the following form can be estimated.

LOSS/DAMAGE = f[ATTRIBUTES of f, ATTRIBUTES of m,
 (commodity k
 mode m) FLOWS of k by m]

Several functional forms should be tested (linear, log-linear, semi-linear) for there is no theoretical reason to prefer one of them.

CHAPTER IV

MODE-SPECIFIC STUDY: RAILROADS

Introduction: a brief presentation of Egyptian railroads.

The geographical environment of Egypt has some features which are very favorable to railroad transportations:

- concentration of economic activity and population on a flat terrain and along a natural axis which is the Nile.
- steady growth of population
- existence of a natural central hub: Cairo
- situation on international trade routes.

The whole set of these factors led to the construction of an extensive railroad network during the nineteenth century. But in addition to war damages, a long era of under-maintenance and low investment resulted in a steady decline in freight transportation and an insufficient growth in passenger traffic. (18)

The Egyptian Railway Authority (E.R.) is a semi-autonomous agency responsible to the ministry of transport and communications. Although it is responsible for day-to-day operations and timetables, it has no commercial freedom. Railway staff are classified according to government grading structure, and wage rates are set by the government. Any

change in tariffs is subject to the approval of the President of the Republic.

The E.R. has 76,486 employees, 23.9% of which belong to the lowest grade (65% in the three lowest grades, out of ten grades).*

The railway system has a total length of tracks of 3905 km., among which 951 are double. The rolling-stock includes:

- 752 locomotives
- 1633 coaches
- 17,606 freight cars.

Around 20% of cars were awaiting maintenance.

In 1975 freight transportation data were:

- 7.80 million tons
- 2190 million-ton-km.

The main item was sugar and molasses.

In 1970/71 the corresponding figure was: 10.43 million tons.

As regard passenger transportation, 1975 data were:

- 305.3 million journeys
- 8831 million passenger-km.

In 1970/71, it used to be: 221.2 million journeys.

*all figures are from the 1977 interim report of the Egypt national Transport Study (see references).

The general trend in freight transportation was far from being offset by the slower growth in passenger service. The result was a deficit of 2.74 million L.* in 1975, whereas in 1970/71, the surplus was: 8.85 million L.

As a conclusion, rehabilitation and adequate maintenance of the existing facilities, as well as an upgrading and renewal of the rolling-stock seem to be the major priorities of railroad transportation, which undoubtedly still play and will continue to play an important role within the Egyptian economy.

1. Main issues in investment policy: a qualitative approach of their impacts on costs and flows.

In the light of the Egypt National Transportation study, the main issues in investment policy which will have to be dealt with within the modelling framework, will be reviewed, from a qualitative point of view.

i. Physical plant.

Track: The Egyptian network is characterized by a huge amount of deferred maintenance on tracks which are mostly very old. Then, although design standards are generally satisfactory, partly due to the fact that because of geographical features there are few important gradients or curves, there is a crucial need for building and renewal. Now physical characteristics on links obviously have impacts upon operations. The number of tracks (single or double), the capacity, connected with the siding and signalling systems, the loading standard, the track lay-out

*L. = Egyptian pound

condition operating options such as speed, frequency, length of trains, power to weight ratio or fuel consumption. This, in turn will have impacts upon the performance level, as summarized by the attributes of the level of service (trip-time, reliability, loss and damage).^{*} Therefore the investment policy will obviously have consequences upon actual modal choices. A simple patching, and the provision of an adequate maintenance level would be able in certain cases to upgrade track characteristics. Besides, another impact of investment in tracks will be additional maintenance costs, as well as new operating expenses due to signalling and communications.

On the other hand, link abandonment can be an important problem because of service requirements imposed upon the Egyptian Railways. Within the unimodal modelling framework the only aspect of such a policy option that can be dealt with is the short-term impact on costs (maintenance and operations). Long-term effects should be treated through a cost-benefit analysis. This point will be developed in a following section.

Yards. These are definitely a crucial component of trip-time reliability. According to the "studies in railroads operations and economics" [19, 20], 32.41% of trip-time variance is due to yards.

^{*}and upon rolling-stock deterioration and safety.

At the moment, in Egypt, there does not seem to be capacity problems, due to the low level of freight transportation flows. Yet yard operations are sluggish due to:

- shortage of locomotives
- damaged cars in the yards
- unsuitable track lay-out.

Consequently yard improvement is definitely a major policy option. There are two types of yards:

- hump yards: cars are initially pushed over a hump.
- flat yards: each car is sorted individually from the string of cars.

The impact of investment in yards will be hopefully a smaller delay due to yard operations, thanks to a reduction of congestion and more adequate track lay-outs.

Signalling and Communications. There is a very close connection between signalling and capacity, particularly in the case of single tracks which prevail in Egypt. Delays en route, due to meets and passes, become an important component of overall trip-time performances. More particularly signal and switch systems directly condition average delays due to sidings. Therefore they are a major area of connection between investment policy, level of performance and at last transportation flows.

N.B.: On the other hand, flows will have an impact on the physical plant through deterioration and subsequent maintenance costs.

Within the framework of the detailed link analysis, as mentioned in Chapter II, this relationship will be studied through flow dependent maintenance of way costs in the GCF.

ii. Rolling Stock.

The second major area of investment in the railroad industry is the rolling-stock. The E.R. policy in the field seems to have been mainly a "run to failure" method. The main consequence of this has been excessive maintenance and operating costs. This feature combined with underinvestment led to an age distribution, the mean of which is very high and to a vehicle availability which is much too low: around 20% vehicles (cars or coaches) are out of order, whereas a reasonable range would be around 5 or 10%. As regards freight cars for example 13% were awaiting scrapping in 1976 and the average age was 24 years. In such a context the impact of investments upon the state of the rolling-stock is twofold:

- to shift the age distribution towards smaller ages.
- to improve vehicle availability.

A consequence of this is to decrease maintenance costs and to improve the level of service.

Besides investments in new cars for example would allow some necessary technical improvements such as car brakes. This in turn will relax constraints upon speed and length of trains. Most rolling-stock (specifically locomotives and first class coaches) is imported to Egypt. This implies additional ownership costs (including a foreign exchange

component) on one hand, and can make the provision of spare parts and consequently vehicle availability very hazardous.

At last there seems to be dramatic shortage of locomotive power (of around 20%). The consequence of this is the cancellation of many trains. Therefore actual frequencies, rather than scheduled ones should be considered as directly impacted by the investment policy as regards locomotives. Besides yards operations would be improved. Either rebuilding or purchase can be considered.

2. Operating regulations, operations and maintenance policies:
a qualitative approach of their impacts upon costs and flows.

i. Operating regulations.

Service regulations: They provide guidelines and can be related to frequency, schedule adherence, load factors, train length, speed, power to weight ratio, weight limits. Although they usually provide but bounds, they can have impacts upon the actual values of these quantities, when they are extreme points of the inequality constraints. In such a case they usually result in an impact on costs.

Equipment regulations: Vehicle specifications, maintenance standards and safety regulations obviously impact corresponding costs.

Labor regulations: This is definitely a very important constraint.

The major components are:

- grading: the grading structure is imposed by the government. It can therefore be interesting to break the labor force into three components.

- top four levels: 9% in 1976
- middle level employees: 26% in 1976
- lowest three grades: 65% in 1976.

The last category mainly includes unskilled manual workers.

- wages: they are set by the government. As regards them, for obvious operational considerations it is certainly more interesting to separate crews from the rest of the labor force.
- work rules: this is again a crucial element. Its major consequences can be crew size requirements and subsequent labor costs; working time limitations. This seems to be the cause of important delays en route, since crews cannot work more than eight hours in a row. Provided it can be dealt with at the scale of a link it will have an impact on trip time; safety standards.
- productivity: productivity is an important indicator of the efficiency of the railroad system, provided adequate units are used. Gross units such as ton-miles per man-hour can be very deceiving, because they do not take into account the size of individual shipment, the length of haul or specific commodity

features. A way of dealing with this problem is to deflate freight revenues by an index of freight rates. Besides passenger miles must be converted into equivalent ton-miles, according to the relative cost levels of the two services. In any case, crude measures of labor-productivity must not hide underlying phenomena such as:

- substitution for capital
- labor services bought from outside
- declining maintenance
- government labor requirements.

Therefore any productivity standard should be treated very carefully.

Environmental regulations and resources consumption: These can result in additional costs particularly as regards fuel emissions and noise level. Anyway environmental issues of that kind do not seem to be a key constraint, particularly in the case of railroad transportation. On the other hand possible fuel consumption constraints, can be an important determinant of the level of service, either as regards fuel quality or even rationing. Besides fuel price is of course a key element of operating expenses.

ii. Operational options.

Linehaul operations: The main options involved are:

- power-to-weight ratio, or number of locomotives per train
- number of cars per train
- train composition as regards car types
- frequency and schedule
- load factor
- speed
- vehicle allocation.

Obviously these options are interrelated. The most binding constraints upon operations are:

- A demand requirement: Egyptian railways have to face demand as it is, which implies a relationship between flows, frequency, load factors and train composition.
- A rolling stock requirement: E.R. must allocate a sufficient number of items (cars or locomotives) to meet service standards. Vehicle availability, which is a key issue in Egypt as we have seen before is a major constraint. The actual way the system works seems to result in numerous train cancellations and subsequent waiting-time for items to be transported.

In addition to these constraints, service standards, as well as physical characteristics of vehicles and links, imply feasible ranges for most of the variables mentioned above.

The impacts of operational options are manifold:

- fuel consumption can vary. A fuel consumption model can quantify these variations, according to the characteristics of the link, of the train, and the operating speed.
- the level of service and consequently the user's cost is directly connected with operating characteristics. Consequently flows will be impacted.
- maintenance costs depend on the intensity of operations. On one hand vehicle maintenance costs are impacted, on the other hand maintenance of way costs vary according to the deterioration which is connected to actual flows, their speed, and their weight.
- crew-cost. On the basis of a cost per train hour crew number, crew costs are impacted by the way operations are organized. Their consideration would tend to longer and less frequent trains.

Yard Operations. They are definitely a key determinant of service quality, as it has been mentioned above. Yard performances are summarized by time spent within yards, which is an important component of any overall trip-time model. It can be dealt with through the probability of making a connection between an inbound train and an outboud one, as a function of the available time in the yard. (Time between actual arrival and actual departure of the individual car considered),

also called P.MAKE analysis. The sequence of operations within a yard are:

- inbound train inspection and preparation for classification
- classification
- assembly of the outbound train
- outbound inspection and preparation for departure.

Delays can occur at each step of the sequence. Major reasons for delay are:

- late arrivals
- congestion
- low priorities
- derailment
- tonnage
- lack of way bills
- cancellation of the outbound train.

Measurable performances that can be included in the analysis are:

- inbound train performance
- hump or initial queues
- assembly time
- outbound train performance
- tonnage left behind.

Operating options can aim at dealing with one or several reasons for delays. They will hopefully reduce the average time spent within the yard or increase the probability of making a connection (P.MAKE),

given an available yard-time. The main elements of yard reliability are summarized on Figure XX.

3. Market regulations and market structure.

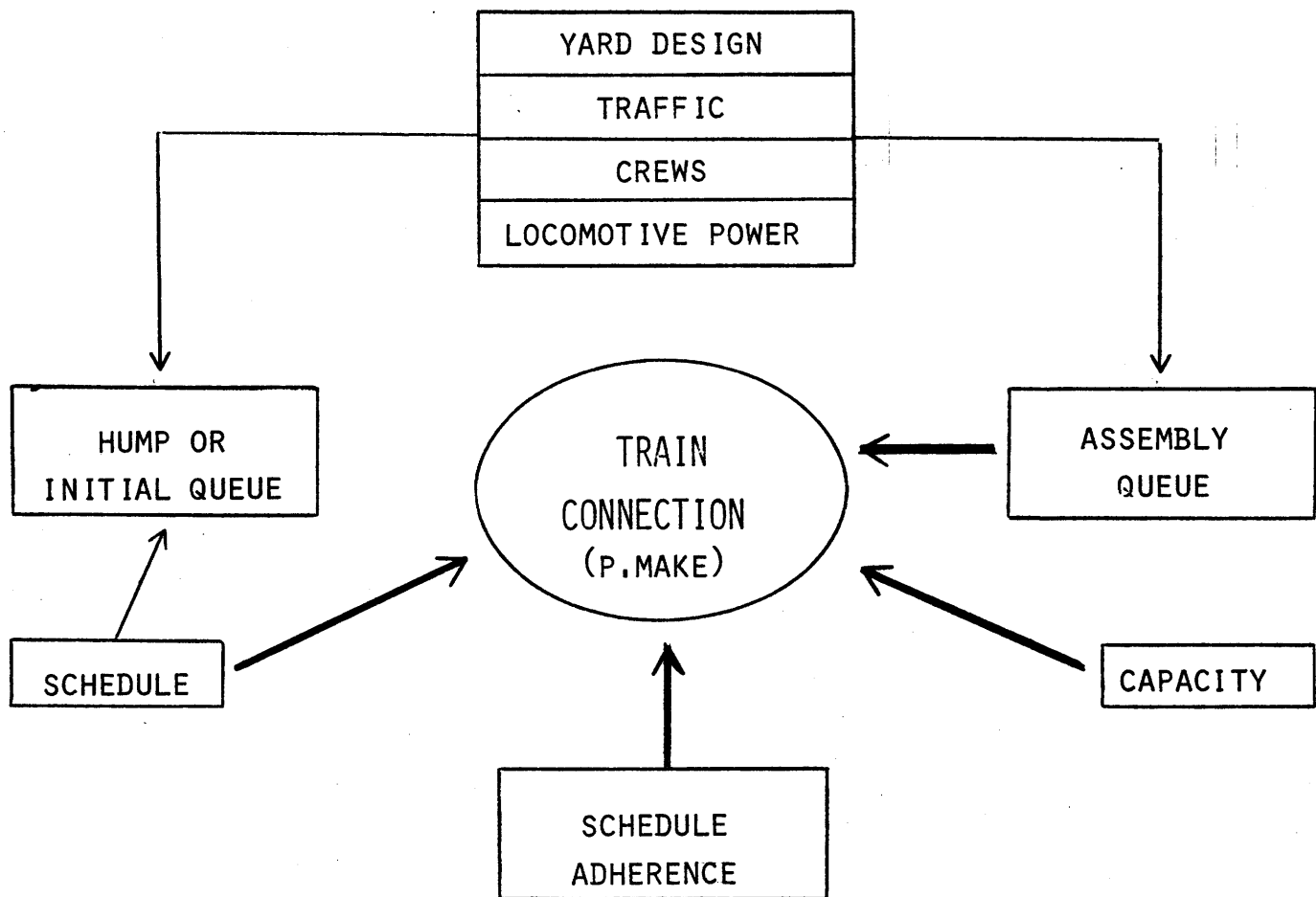
Although it is not the main focus of this thesis, the impact of market regulations upon transportation costs and flows should be mentioned for the sake of completeness. A detailed list of them is given in Appendix A. Besides, due to the specific situation of the Egyptian Railways and the monopoly they have within the railroad industry, some issues related to market structure are not relevant.

Entry and cost regulations. They do not apply to the Egyptian situation, for the reasons given above.

Price regulations. The specification of a tariff structure within the unimodal framework allows to deal with these regulations. As it has been mentioned before, any changes in fares is subject to the approval of the government. Besides the permeability constant can be used if fares are to be related to operator costs.

Taxes and subsidies. All prices included within the GCF have a tax component, which consequently is explicitly taken into account. All other kinds of taxations (linked to the rate of return, for example) can be considered only within the framework of the detailed link analysis

FIGURE XX
Yard Performance Components



which has been mentioned before. An accounting procedure can then allow to evaluate actual costs, revenues and subsequent taxes on one hand, and possible subsidies linked to deficits on the other hand. In any case, the link level which is imposed by the very structure of the unimodal framework is not adequate. This study will have to be done at the network level.

Rate of return regulations. They are not relevant to this case, being implicitly dealt with through price regulations.

As a conclusion, because of the institutional framework of the E.R., market regulations do not seem to be a key element of the unimodal study. The market structure is straight forward and fixed. Still constraints due to governmental control (particularly in the field of tariffs), are important determinants of the level of service as perceived by users.

4. Policies which cannot be handled within the unimodal models.

The very definition of the unimodal modelling framework contains its limits. It is a link level analysis, based on operator's and user's costs, which have to be quantified on a yearly basis. Consequently the main types of issues which cannot be totally or even partially handled are:

Implicit policy issues. The transportation system, because of "type 1" relationships mentioned in Chapter I is influenced by the whole activity system. Therefore many policy issues are not explicitly formulated as regards their specific impacts upon transportation activities.

Broad national economic or social goals, although explicitly (at least in most cases) stated within the political or economic arenas, become implicit and hardly modelable underlying constraints to the transportation sector. They must be analyzed anyway, because they can be keys to the global consistency of transportation policies.

Network or system level policy issues. Because of the link framework of unimodal models, issues relevant at a path, a network or a system level can hardly be taken into account. In most cases it is very difficult to allocate partial effects to links. Global constraints to the assignment can be used.* An example could be changes of crews. If the trip time within a link is less than eight hours, then delays due to changes in crews cannot be allocated to a specific link along the path, if the overall O.D. trip-time exceeds eight hours.

Long-term options. Because of the yearly updating, it is certainly difficult to take into account long-term options. Link abandonment policy for example involves a long-term analysis which cannot be made within the modelling framework. Besides investment policy raises

*either physical or non-physical

a whole set of problems, either behavioral or economic and financial which cannot be dealt with such as the optimal time framework of an investment, or the connection between investment level and subsidies.

Firm-level issues. This problem is less acute in the railroad industry because of the monopoly of E.R. But as it has been mentioned above, link is not an adequate level as regards accounting analysis for example, network overall structure, or rolling stock allocation, all the more so when an optimization process occurs at a global level.

Non-modellable issues. Most issues connected with organization, management, marketing problems for example can hardly be modelled. The efficiency of one of the three elements mentioned above, although a crucial policy issue is very difficult even to define, a fortiori to quantify within a model. As far as it is possible, proxies will have to be found, or a qualitative approach to be used.

Conclusion and possible ways of improving policy sensitivity. There is definitely a trade-off between policy-sensitivity and computational feasibility and efficiency. The modelling framework must be flexible enough to deal with policies which have not been considered at first sight. On the other hand it is certainly not worth taking into account policies, the impacts of which are minor or unclear.

When no analytical framework is available, there are several ways of quantifying policy-options.

- Parameter adjustment through a trial and error process. A whole set of reasonable values can be tested within the model, as user-specified inputs. A sensitivity analysis and comparison with significant results should allow to select the best value.
- Use of proxy-variables. Policies can be evaluated through the impacts they have upon key-variables. Once these have been identified they can be quantified through all the methods mentioned in this section.
- Classification. When the exact value of a parameter, or the exact characteristics of an operational element for example cannot be determined, classification can be used. A class will be defined by typical, appropriate values or ranges of values. For example a signalling and switching system can result in several typical delays due to meets and passes. Instead of using individual data and measures, systems will be classified into several categories. The level of detail can vary dramatically. It allows a great flexibility in the use of the model as well as in computational tasks and data requirements.
- Implicit treatment. When numerical or analytical relationships cannot be determined, effects of supposedly explanatory variables are implicitly included in the dependent variable. For example the frequency of breakdown or fuel consumption obviously depend on the quality of preventive maintenance, although these relationships cannot probably be quantified.

Obviously, because of theoretical computational or data requirements many policies will not be handled at all within the modelling framework. It is definitely a crucial task for future users of the model to be able to select the policies they want to test. Hopefully the structure of the model will be flexible enough to allow the inclusion of most relevant policies.

5. Analytical formulation.

The analytical design of the railroad cost model will involve a simulation of operations, and several submodels, the results of which will be used as inputs of the Generalized Cost function.

i. Submodels

a. Fuel consumption.

The approach is similar to, but simpler than, the "train performance calculators" which have been used by a number of railroads. There are three main sources of fuel consumption:

1. fuel used in overcoming air, wind and rolling resistance on straight, level track;
2. fuel used in climbing grades;
3. fuel used in acceleration.

1. The basic relationship is:

$$[1] \quad \boxed{\text{FUEL} = \alpha [\text{TRESIS} \times \text{MILES} \times \text{GPHPH}]}$$

Where: FUEL = fuel consumed in gallons

TRESIS = train resistance in pounds

MILES = miles traveled

GPHPH = gallons per horsepower hour

α : constant; with these units α usually equals

$$\left(\frac{1}{375} \right)$$

Now: [2]

$$\boxed{\text{RRESIS} = \alpha_1 + \frac{\alpha_2}{\text{WPA}} + \alpha_3 \times V + \frac{\alpha_4 \times A \times V^2}{\text{WPA} \times N}}$$

Where: RRESIS = rolling and air resistance in pounds per ton.

WPA = weight per axle in tons.

V = speed in miles per hour.

N = number of axles per car.

A = cross section of a car in square feet.

$\alpha_1, \alpha_2, \alpha_3, \alpha_4$: constants.

Different sets of coefficients have been used in the literature.

The Harvard Brookings model uses: (3)

$$\alpha_1 = 1.3 \quad \alpha_2 = 29 \quad \alpha_3 = 0.03 \quad \alpha_4 = \begin{cases} 0.0024 & \text{for the first car} \\ 0.0005 & \text{for the following} \end{cases}$$

The American railway engineering association uses: (9)

$$\alpha_1 = 0.6 \quad \alpha_2 = 20 \quad \alpha_3 = 0.01 \quad \alpha_4 A = K = \begin{cases} 0.07 & \text{for carload} \\ 0.3 & \text{for locomotive} \\ 0.16 & \text{for TOFC} \end{cases}$$

Therefore the train total rolling and air resistance will be the sum of the resistances of all its components:

$$[3] \quad \text{RTRESIS}' = \sum_{i=1}^{n\ell} \omega \ell_i \times \text{RRESIS}[\text{LOCO}_i] + \sum_{j=1}^J \text{NCAR}_j \times \text{RRESIS}[\text{CAR}_j] \times (\text{CAP}_j \times \text{LF}_j + W_j)$$

where: RTRESIS' = total air and rolling resistance in pounds.

$n\ell$ = number of locomotives per train

$\omega \ell_i$ = weight of locomotive i

$\text{RRESIS}[\text{LOCO}_i]$ = resistance of locomotive i in pounds per ton

J = number of car-types

NCAR_j = number of cars of type j per train

CAP_j = capacity of cars of type j

LF_j = load factor of cars of type j

W_j = weight of cars of type j (empty).

$\text{RRESIS}[\text{LOCO}_i]$ and $\text{RRESIS}[\text{CAR}_j]$ are computed according to equation [2].

A way of dealing with wind resistance which has not been taken into account, is to inflate the coefficient K by a given percentage. (20% seems to be a reasonable value according to the literature.) The final result is then: RTRESIS

In equation [2], one must use V and V^2 . Since they are obviously not constant, averages must be used, but over distance. Since this measure is not usually available, it can be related to the average over time.

$$\begin{cases} E_d(V) \approx E_t(V) + 10 & (\text{miles}) \\ \text{if } \text{Var}_d(V) \approx 400 \end{cases}$$

These values seem to be reasonable and can be adjusted.

besides: $E_d(V^2) = [E_d(V)]^2 + \text{Var}_d(V)$

where: $E_d(V)$ = average speed over distance

$E_t(V)$ = average speed over time

$\text{Var}_d(V)$ = variance of speed over distance.

- In equation [2]: $\begin{cases} E_d(V) \text{ will be used for } V \\ E_d(V^2) \text{ will be used for } V^2. \end{cases}$

2. Fuel used climbing grades:

[4]

$$\text{GTRESIS} = \beta \times \text{PCTGD} \times \text{TW}$$

where: GTRESIS = train resistance due to grade in pounds
 PCTGD = per cent grade
 TW = total train weight (locomotive + cars)
 β = constant, usually $\beta = 20$

assuming that all locomotives have the same weight:

$$TW = n\ell W\ell + \sum_{j=1}^J NCAR_j [CAP_j \times LF_j + W_j]$$

where: $n\ell$: number of locomotives
 all other variables defined above.

3. Fuel used in accelerations. This consumption does not seem to be significant compared to the two other ones. Anyway it can be calculated this way:

- if AFUEL(V) is the amount of fuel necessary to accelerate from 0 to V miles per hour:

the kinetic energy of the train in horsepower hours is:

$$E = \frac{6.75 \times 10^{-5}}{2} \times TW \times E_d(V^2).$$

Since the amount of fuel consumed per horsepower hour is GPHPH:

$$AFUEL(V) = E \times GPHPH$$

then:

[5]

$$ATFUEL = AFUEL(V) \times \frac{MILES}{D}$$

Where: ATFUEL = fuel consumption due to acceleration (gallons)
D = average interval between two "stop equivalents"

A stop equivalent is defined as either an actual stop, or a sequence of slow-down-acceleration roughly equivalent to a stop. A reasonable average estimate of the number of stop-equivalents should be made on a given link. (50 miles for D has been used in the literature.)

Total fuel consumption is then:

$$[6] \quad \text{FUEL} = \alpha \times \text{GPHPH} \times \text{MILES} \times [\text{RTRESIS} + \text{GTRESIS}] + \text{ATFUEL}$$

b. Trip-time.

Because both trip-time and reliability are involved in the model described in chapter II, there is definitely a need for the whole trip-time distribution over a link. There are two different types of distributions to consider. Those concerning line-haul segments, and those concerning yards.

1. Linehaul segments.

The average value of OD (i.e. without intermediate yard) trip-time on a linehaul segment can be decomposed in several components which reflect different operating policies.

$$\text{TT} + \frac{\text{DIS}}{\text{SPEED}} + \text{ADR} + \text{AWT} + \text{AHT} + \text{ExACT}$$

where: TT = travel-time (overall O-D travel time)
 DIS = length of haul
 SPEED = operating speed
 ADR = average delay en route
 AWT = average waiting time at terminals
 AHT = average handling time at terminals
 $E = 0$ if $[TT - EACT] \leq 8$ hours
 1 if $8 < [TT - EACT] \leq 16$
 \vdots
 k if $8k < [TT - EACT] \leq 8(k+1)$
 (k: integer)
 ACT = average delay due to change of crew.

- Average delay en route: In the case of single-track link they can be calculated more precisely. The time-space diagram of a single track link is shown on Figure XXI.

The number of trains encountered by an outbound train is given by:

$$\frac{FREQU_I}{24} [RT_I + RT_O]$$

where: $FREQU_I$ = frequency of inbound trains (per day)

RT_I, RT_O = running times (inbound and outbound)

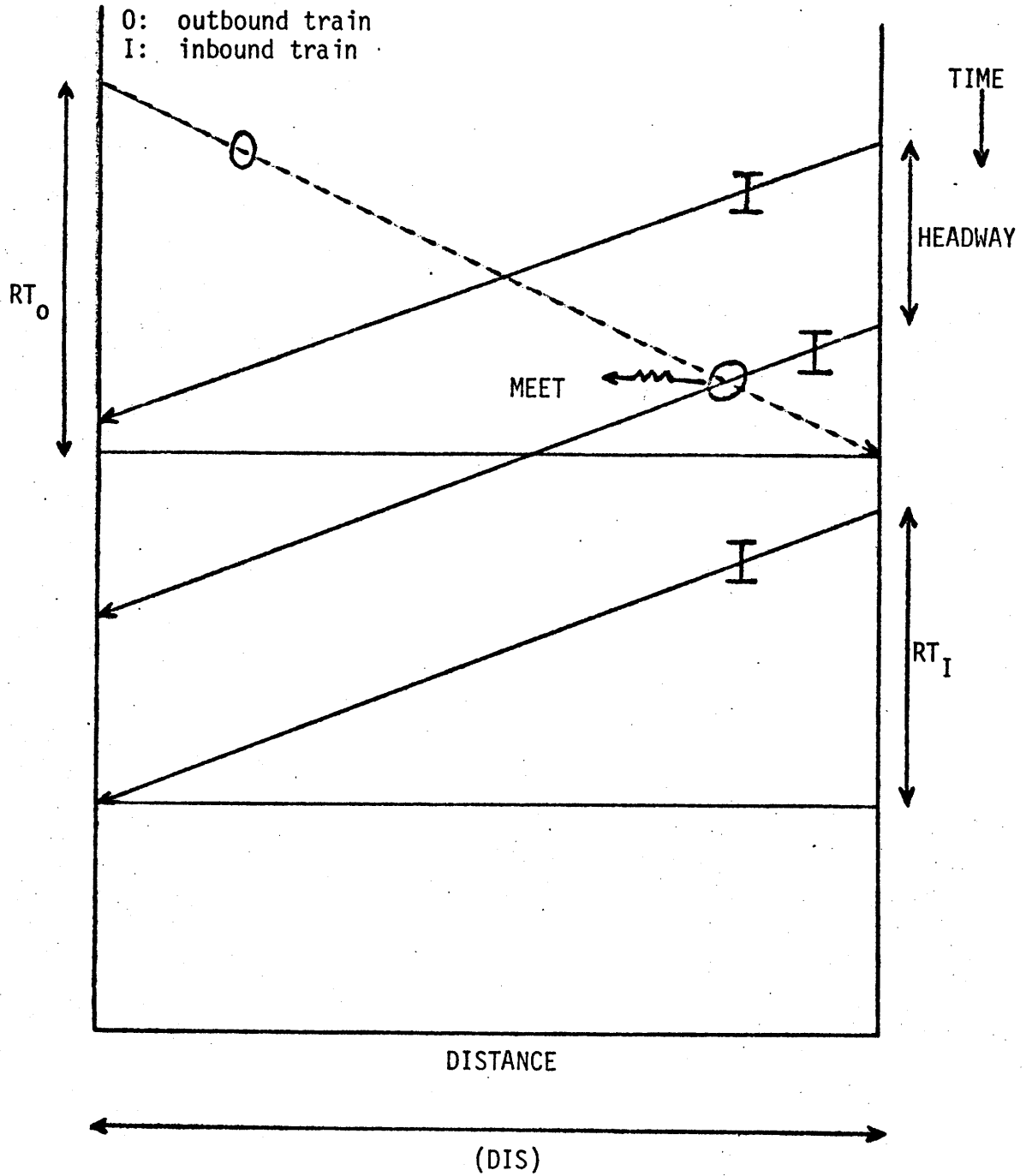
$$RT = \frac{DIS}{SPEED} + ADR$$

if K is the average delay per meet:

let us call $\frac{DIS}{SPEED} = t$

FIGURE XXI

TIME-SPACE DIAGRAM OF A SINGLE TRACK LINK



then:

$$RT_0 = t_0 + K \times \frac{FREQU_I}{24} [RT_I + RT_0]$$

$$RT_I = t_I + K \times \frac{FREQU_0}{24} [RT_I + RT_0]$$

the solutions of this system are:

$RT_I = \frac{t_I - \frac{K}{24} [t_I \times FREQU_I - t_0 \times FREQU_0]}{1 - \frac{K}{24} [FREQU_I + FREQU_0]}$
$RT_0 = \frac{t_0 - \frac{K}{24} [t_0 \times FREQU_0 - t_I \times FREQU_I]}{1 - \frac{K}{24} [FREQU_I + FREQU_0]}$

The average delay per meet K can be written this way:

$K = ST + WT$

Where: ST = switching time associated with the switch type
 WT = waiting time associated with the signal type.

The average delay per meet depends on the way trains are dispatched in the two directions. In the worst case, one train can have to wait for the other one to travel the whole distance between two sidings. In the best case, trains meet at the level of a siding, and there is no waiting-time. Therefore the average waiting time can range from 0 to half the running time between two sidings.

- Average waiting-time:

$$AWT = f[\text{frequency, car availability}]$$

One must consider the actual frequency, rather than the scheduled one, because of train-cancellations which occur very often in Egypt.

- Average handling-time at terminals:

$$AHT = f[\text{available labor-force, volumes of various commodities carried}]$$

Typical handling-times can be determined according to the available labor-force, the degree of automation, and the volumes of different commodities handled; it can be more simply related to train length, or total volume, if an average handling-time per car or per ton is available.

As regards variances, there is no way of computing them through analytical formulae such as those used above. Therefore they will have to be calculated from observed data.

Once means and variances are available, the information needed in the user's cost component of the GCF are gathered, as regards line-haul segments.

- Remark:

An alternative way of dealing with trip-time distributions would be to perform statistical tests based on observed or computed means and variances. Goodness of fit tests, for example, could be used to check whether particular distributions (specifically normal or gamma distributions

seem to be adequate) can represent trip-time accurately.

2. Yards.

The observation of actual data related to yard performances, as shown on Figure XXII, have suggested non-linear functional relationship relating the percentage of cars on schedule (as a proxy for the probability of making a connection: P.MAKE) to the available yard time defined this way:

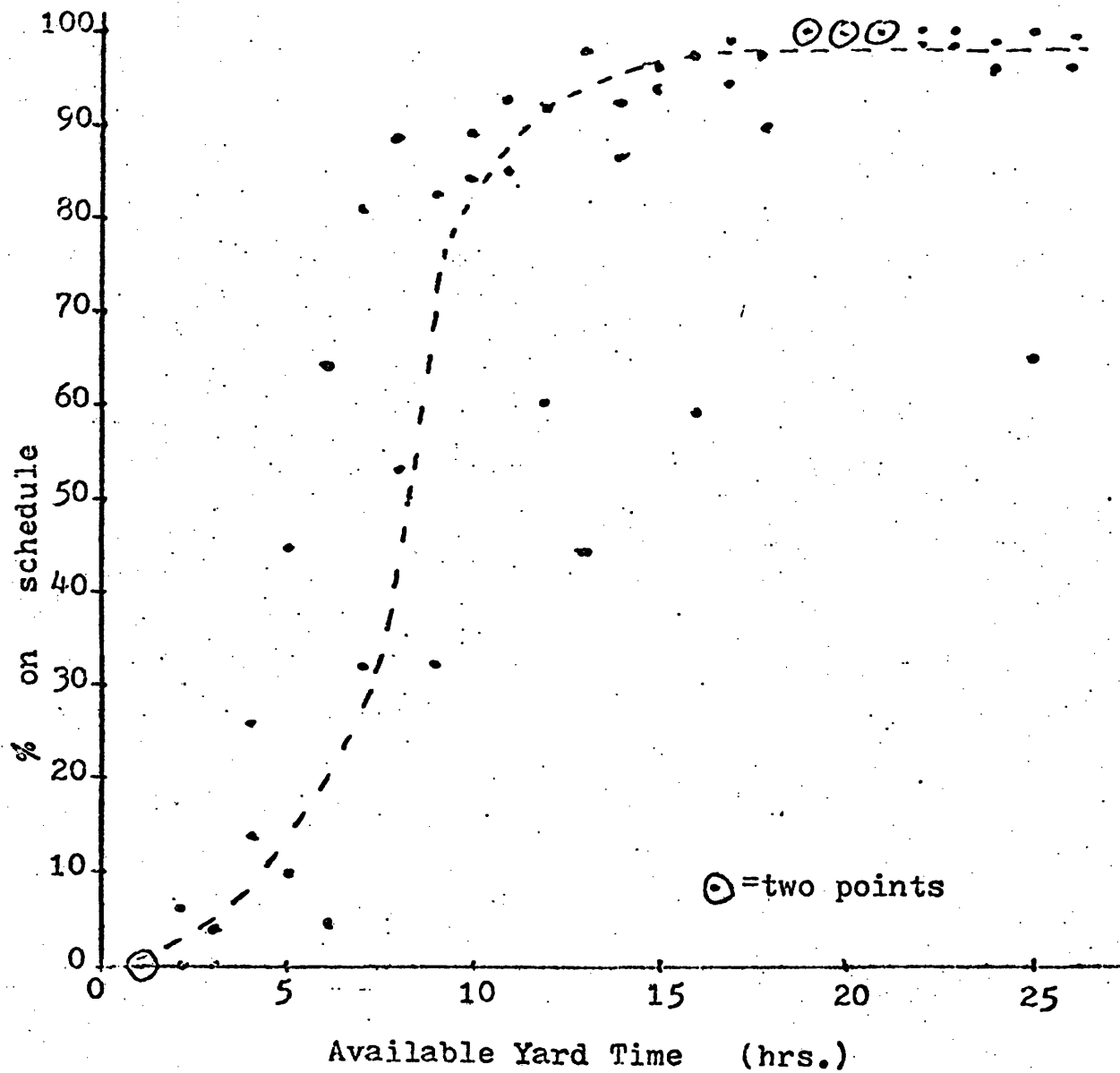
$$\text{AVAIL} = \begin{array}{c} \text{ACTUAL DEPARTURE TIME} \\ \text{(outbound train)} \end{array} - \begin{array}{c} \text{ACTUAL ARRIVAL TIME} \\ \text{(inbound train)} \end{array}$$

The underlying meaning of the main three parts of a typical P.MAKE curve are shown on Figure XXIII.

The three main components are then:

- the minimum available yard-time for which the probability of making a connection is greater than zero. It is the minimum time required to process a car and therefore is a measure of the efficiency of the yard.
- the slope of the curve. An efficient, uncongested yard will have a P.MAKE curve that rises rapidly from the minimum required yard time. It means that a few cars require more than this time.
- the shape of the upper tail. It indicates the importance of great delays such as those caused by cancellation or no-bill.

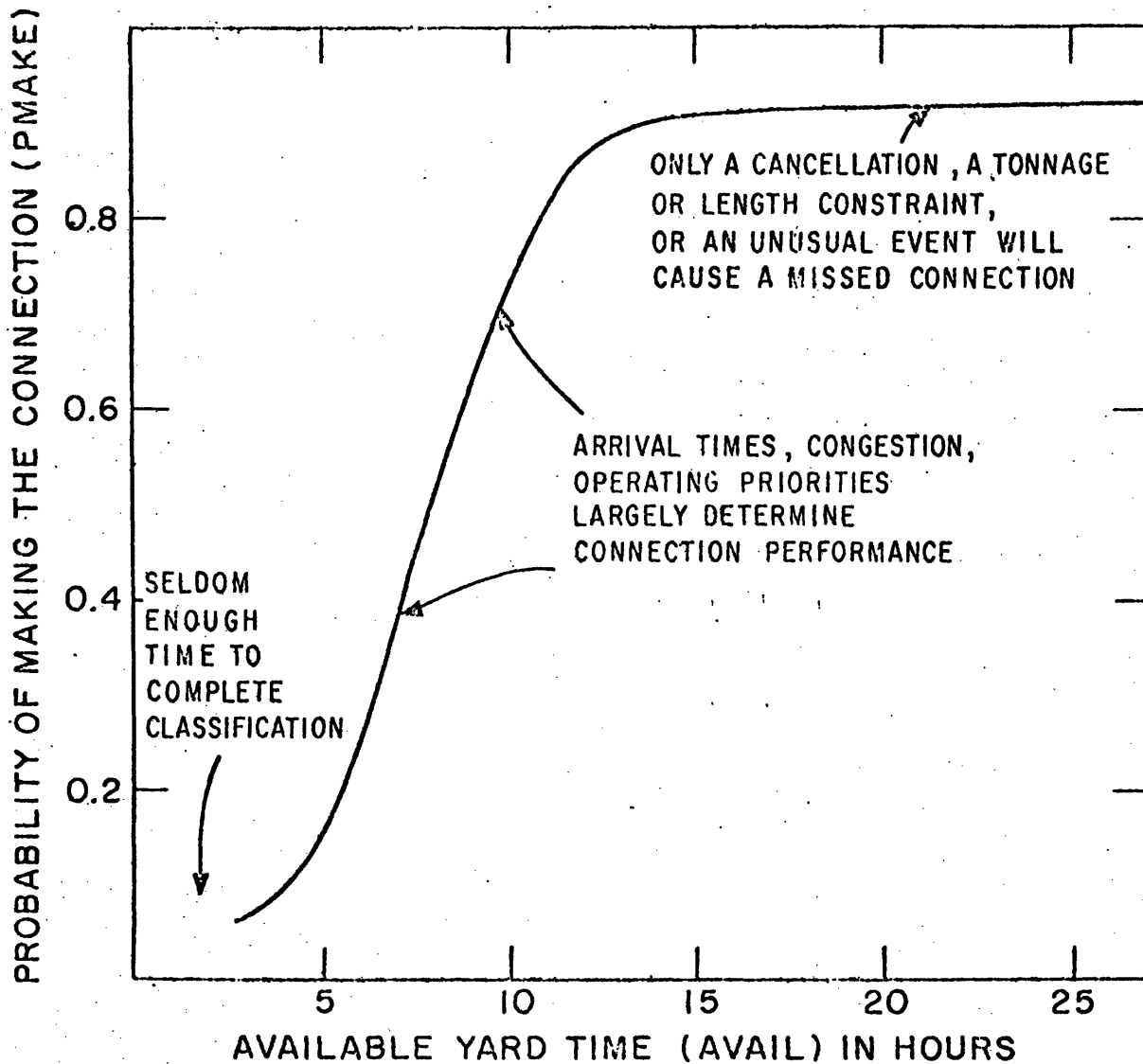
FIGURE XXII
Cars Moving on Schedule
vs.
Available Yard Time



Source: Reid, O'Doherty, et.al.;
Tables A-XII and A-XVI

FIGURE XXIII

PMAKE AS A FUNCTION OF AVAIL



The observation of actual data have led to the conclusion that typical relationships were not linear. Consequently several functional forms have been used in the literature. There is no theoretical reason to prefer one of them. All of them should be tested on available data. A specific functional form can be chosen but for statistical reasons.

The main ones are:

- THE FULL LOGIT MODEL:

$$P.MAKE_1 = \left[1 + \exp[-(a_0 + a_1 AVAIL + \sum_{i=2}^N a_i X_i)] \right]^{-1}$$

- THE HYBRID MODEL:

$$P.MAKE_2 = a_0 + a_1 \left(\frac{1}{1 + \exp[-\alpha AVAIL + \beta]} \right) + \sum_{i=2}^N a_i X_i$$

- THE LINEAR PIECEWISE APPROXIMATION:

$$P.MAKE_3 = a_0 + a_1 AVAIL_1 + a_2 AVAIL_2 + \sum_{i=3}^N a_i X_i$$

where:

$$AVAIL_1 = \begin{cases} AVAIL & \text{if } AVAIL < A \\ A & \text{if } AVAIL > A \end{cases}$$

$$AVAIL_2 = \begin{cases} 0 & \text{if } AVAIL < A \\ AVAIL - A & \text{if } AVAIL > A \end{cases}$$

The value of A has to be determined as well as the other parameters a_i .

The X_i 's represent independent variables. AVAIL is one of them but has been separated from them since the usual graphical representation uses fixed X_i 's and is simply P.MAKE as a function of AVAIL.

The main independent variables are: (in addition to AVAIL)

- the standard deviation of the arrival time of inbound train
- the standard deviation of the departure time of outbound train
- the average volume of traffic per day involved in the connection
- the average length of the outbound train
- load or empty indicator (0 or 1)
- time of the day indicator (n subdivisions of the day: one binary variable for each subdivision)
- priority indicator: -1, 0, or 1
- average horsepower per ton ratio
- average daily peaking factor, ratio of peak volume to average volume (over the subdivisions of the day)
- average weekly peaking factor: ratio of the busiest day volume to the average daily volume.

These variables have been used, separately, or together in actually calibrated models. This is of course a very broad list of possible variables to be considered.

Graphical representations of the three models are given on Figures XXIV and XXV.

FIGURE XXIV

COMPARISON OF THREE PMAKE MODELS

A. TYPICAL CONNECTION INVOLVING A FEW CARS

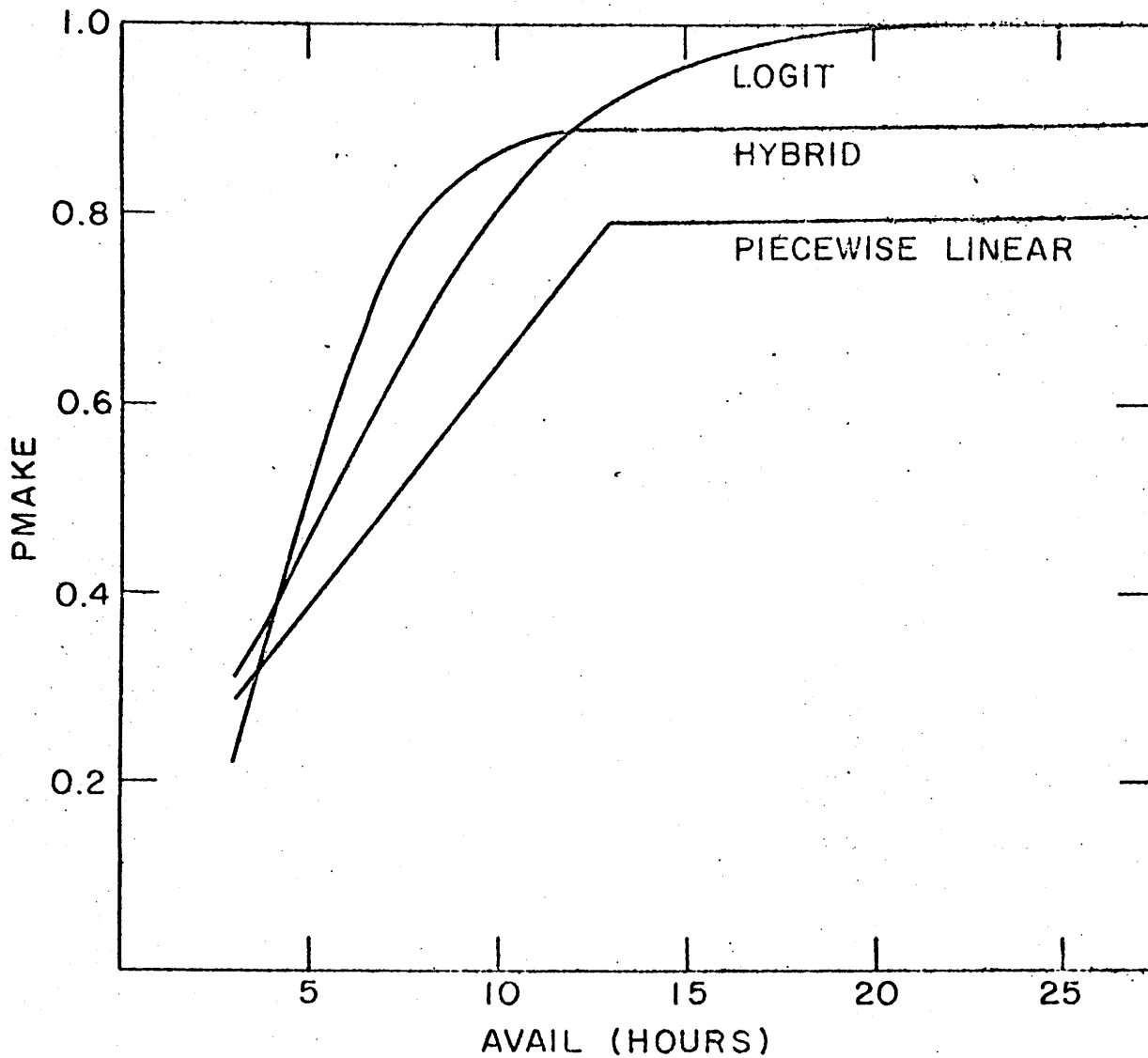
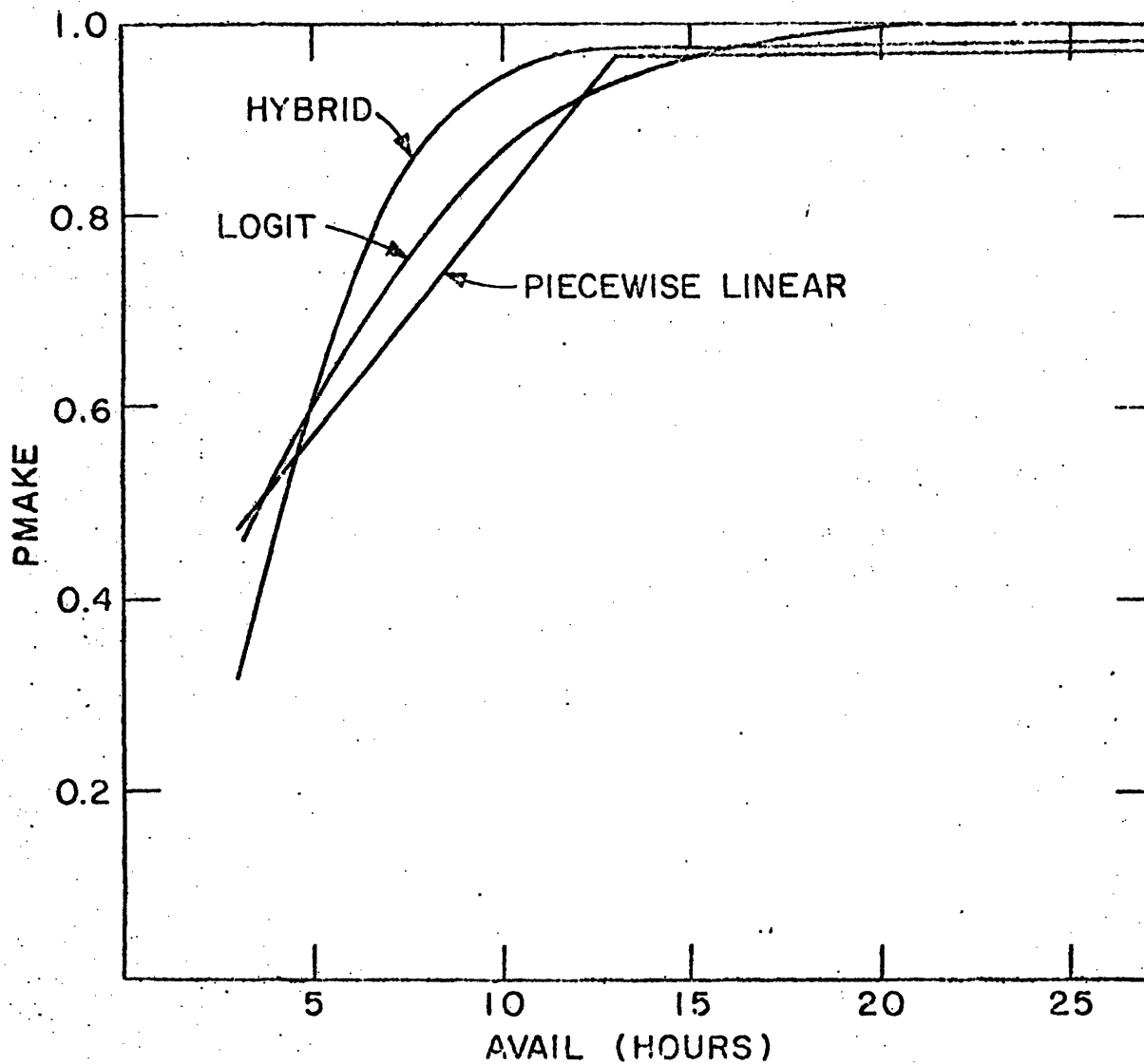


FIGURE XXV

COMPARISON OF THREE PMAKE MODELS

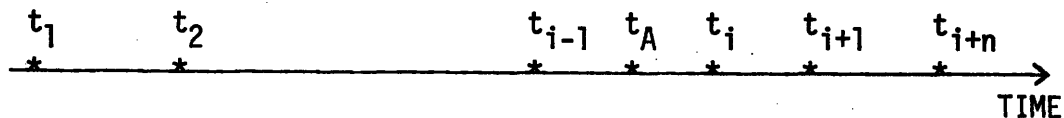
B. TYPICAL CONNECTION INVOLVING MANY CARS



Applications of P.MAKE analysis.

- probability distributions of yard times:

Let us represent the average actual departure times on a time axis, and let t_A be the arrival time of the inbound train, with a probability $p[t_A]$



t_k : average actual departure time of the outbound train.

If $\underline{P}[t]$ is the probability of making a connection in t hours, having arrived at t_A :

$$\underline{P}[t_i - t_A] = \text{P.MAKE}[t_i - t_A] \times p[t_A]$$

$$\underline{P}[t_{i+1} - t_A] = (1 - \text{P.MAKE}[t_i - t_A]) \times \text{P.MAKE}[t_{i+1} - t_A] \times p[t_A]$$

More generally:

$$\underline{P}[t_{i+n} - t_A] = \prod_{k=0}^{n-1} (1 - \text{P.MAKE}[t_{i+k} - t_A]) \times \text{P.MAKE}[t_{i+n} - t_A] \times p[t_A]$$

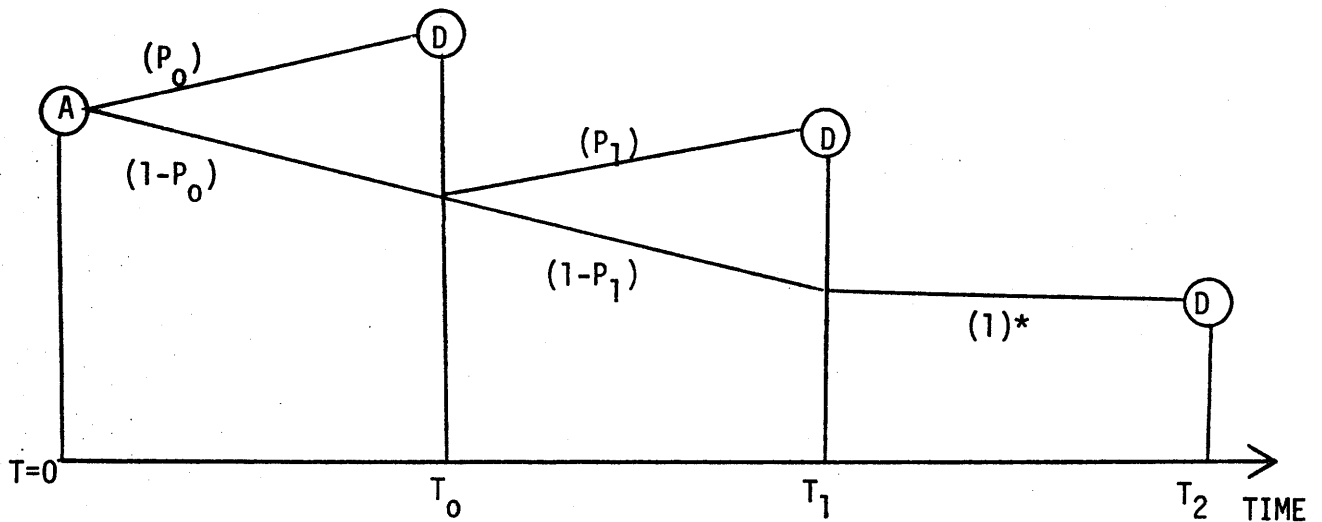
- mean yard-time.

To calculate mean yard-time, one has simply to consider a spanning tree such as that shown in Figure XXVI. One has an assumption to make as regards the maximum number of missed connections. On the figure the

FIGURE XXVI

DIFFERENT PATHS AND CORRESPONDING PROBABILITIES

- at most two missed connections
- departures at T_0 , T_1 , T_2



* since at most two connections are missed.

$$P_0 = P.\text{MAKE}[T_0]$$

$$P_1 = P.\text{MAKE}[T_1]$$

Missed Connections	Yard-Time	Probabilities
0	AVAIL = T_0	$P.\text{MAKE}[T_0] = P_0$
1	AVAIL + $t_1 = T_1$	$(1-P.\text{MAKE}[T_0]) \times P.\text{MAKE}[T_1] = (1-P_0) \times P_1$
2	AVAIL = $t_2 = T_2$	$(1-P.\text{MAKE}[T_0]) \times (1-P.\text{MAKE}[T_1]) = (1-P_0) \times (1-P_1)$

assumption is that any car cannot miss more than two connections; the yard times can then be:

AVAIL

AVAIL + t_1

AVAIL + t_2

The inbound train is supposed to arrive at $t=0$. Outbound train departures occur at AVAIL, AVAIL + t_1 , AVAIL + t_2 .

The mean yard time is then:

$$T = P.MAKE[AVAIL] \times (AVAIL) + (1 - P.MAKE[AVAIL]) \times P.MAKE[AVAIL + t_1] \times (AVAIL + t_1) + (1 - P.MAKE[AVAIL + t_1]) \times (1 - P.MAKE[AVAIL]) \times (AVAIL + t_2).$$

$$T = AVAIL + (1 - P.MAKE[AVAIL]) \times \left(t_2 + P.MAKE[AVAIL + t_1] \times (t_1 - t_2) \right)$$

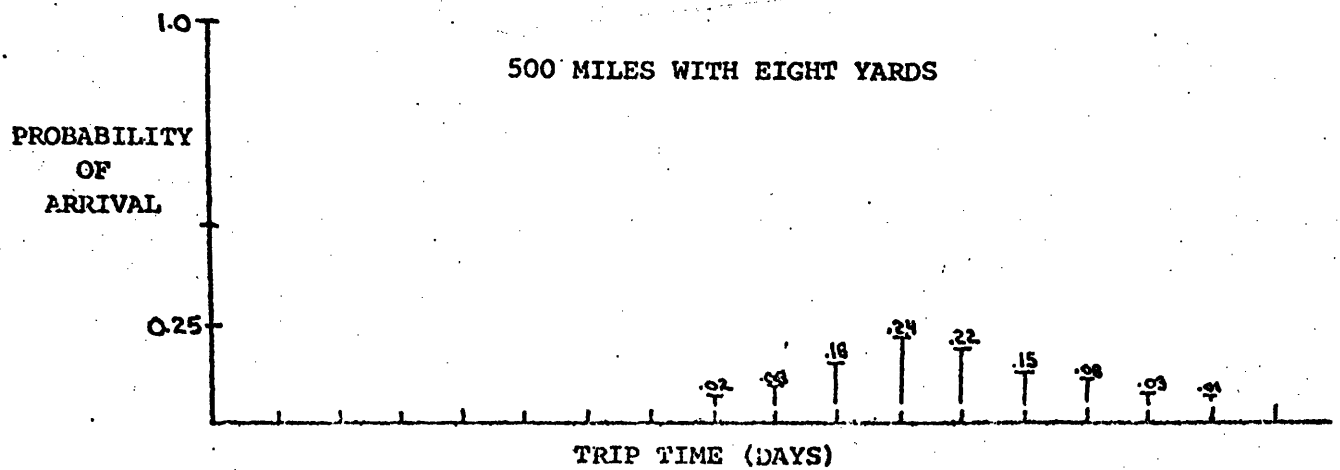
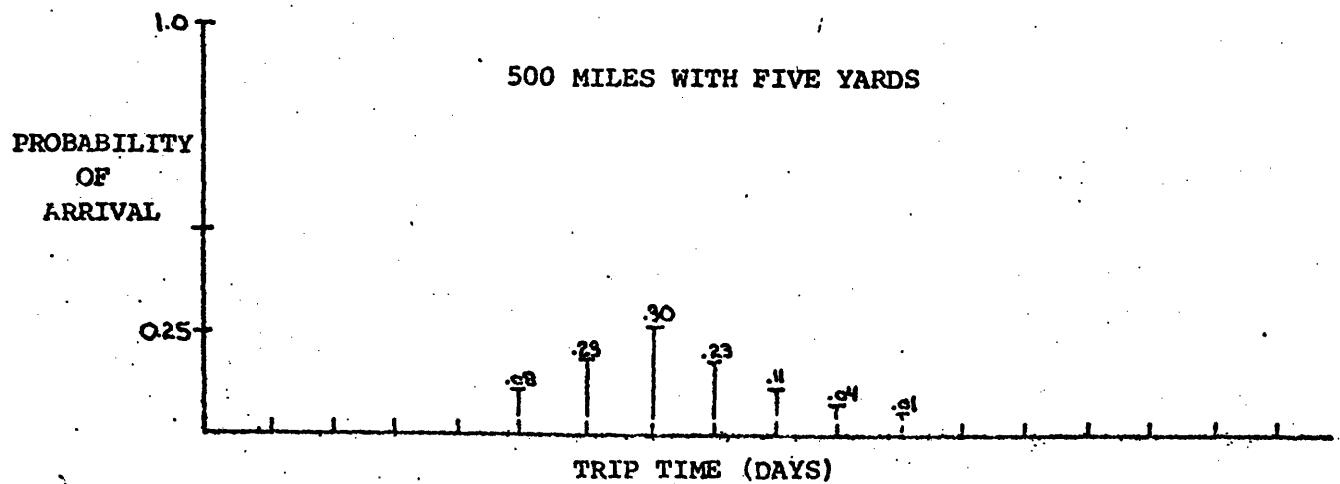
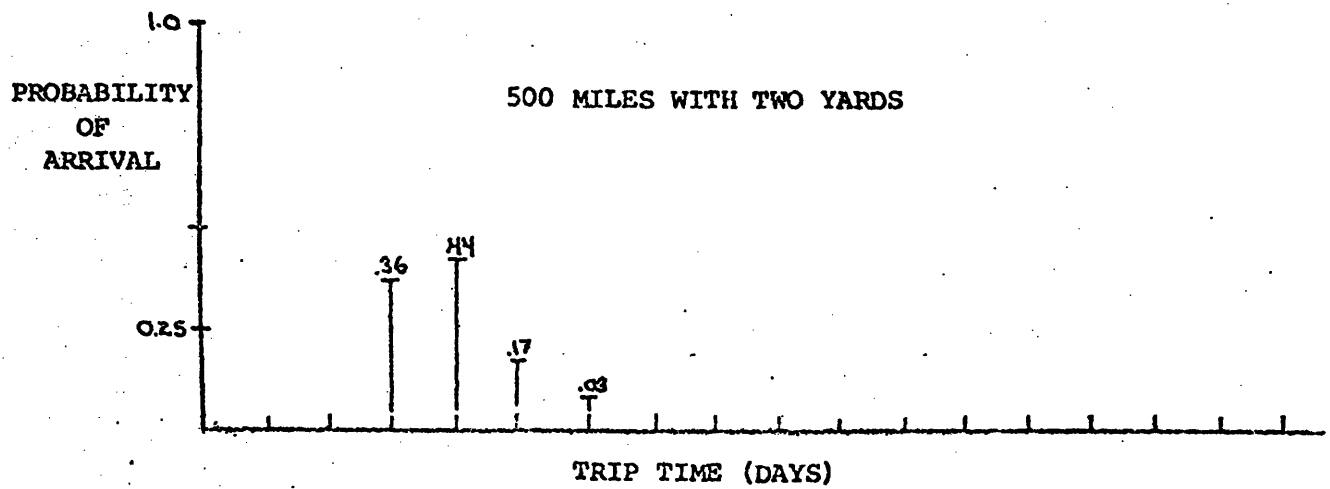
The combination of several linehaul segments and yards allows to compute overall O.D trip-time distribution. Possible outputs are shown on Figure XXVII, which besides shows the influence of yards on both mean trip-time and variance.

c. Rates

(i) Freight tariffs have remained unchanged since 1957. Commodities are

FIGURE XXVII

THE EFFECT OF NUMBER OF CLASSIFICATION YARDS ON TRIP TIME FOR
A 500 MILE RAIL SYSTEM WITH DAILY DEPARTURES FROM EACH YARD



divided into 11 tariff classes. Each commodity is assigned to one class for less than carload shipments and to another one, generally the following one, for car load traffic. The general tariff structure is based on ton-kilometer:

Let us call α the rate for distances between 0 and 250 km.

then:

distance (kms.)	rate (per ton-km.)
0 - 250	α
251 - 500	$\frac{\alpha}{2}$
> 500	$\frac{\alpha}{4}$

Graphically the function is represented on Figure XXVIII where a sample of tariffs can be found.

A continuous function can be used to approximate the actual tariff. It can be a piecewise linear approximation, for example:

$$(1) \quad \begin{aligned} \text{RATE} &= \alpha - \beta \times (\text{DISTANCE}) \quad \text{if DISTANCE} [0, 500+D] \\ \text{RATE} &= \frac{\alpha}{4} \quad \text{if DISTANCE} > 500+D \end{aligned}$$

D and β would have to be chosen so that:

$$\bullet \quad \frac{\alpha}{2} \leq \text{RATE} [250] \leq \alpha$$

$$\bullet \quad \frac{\alpha}{4} \leq \text{RATE} [500] \leq \frac{\alpha}{2}$$

$$\text{RATE} [500 + D] = \frac{\alpha}{4}$$

TARIFFS: FREIGHT



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A second approximation can be a hyperbole form:

(2)

$$\text{RATE} = \frac{\alpha \left[\frac{\text{DISTANCE}}{4} + \beta \right]}{\text{DISTANCE} + \beta}$$

so that when

$$\text{DISTANCE} = 0 \Rightarrow \text{RATE} = \alpha$$

when

$$\text{DISTANCE} \rightarrow \infty \Rightarrow \text{RATE} \rightarrow \frac{\alpha}{4}$$

Here again β would have to be chosen so that:

$$\frac{\alpha}{2} \leq \text{RATE} [250] \leq \alpha$$

$$\frac{\alpha}{4} \leq \text{RATE} [500] \leq \frac{\alpha}{2}$$

or:

$$\frac{\alpha \left[\frac{250}{4} + \beta \right]}{250 + \beta} \geq \frac{\alpha}{2} \Rightarrow \beta \geq 125$$

and

$$\frac{\alpha \left[\frac{500}{4} + \beta \right]}{500 + \beta} \leq \frac{\alpha}{2} \Rightarrow \beta \leq 250$$

then

$$125 \leq \beta \leq 250$$

(ii) The same tariff structure exists for passengers. In this case the distance limits are: 40, 100 and 300 km. Besides there are basically five categories:

- first class with air conditioning
- first class without air conditioning
- second class with air conditioning
- second class without air conditioning
- third class.

Since basically the functional form is the same as for freight, the same approximations can be used, either piece-wise linear or hyperbolic.

The tariff structure is given on Figure XXIX, as it was in 1976.

d. Loss and Damage.

The main issues have been described in Chapter III, section 4. There may be a great problem of data availability.

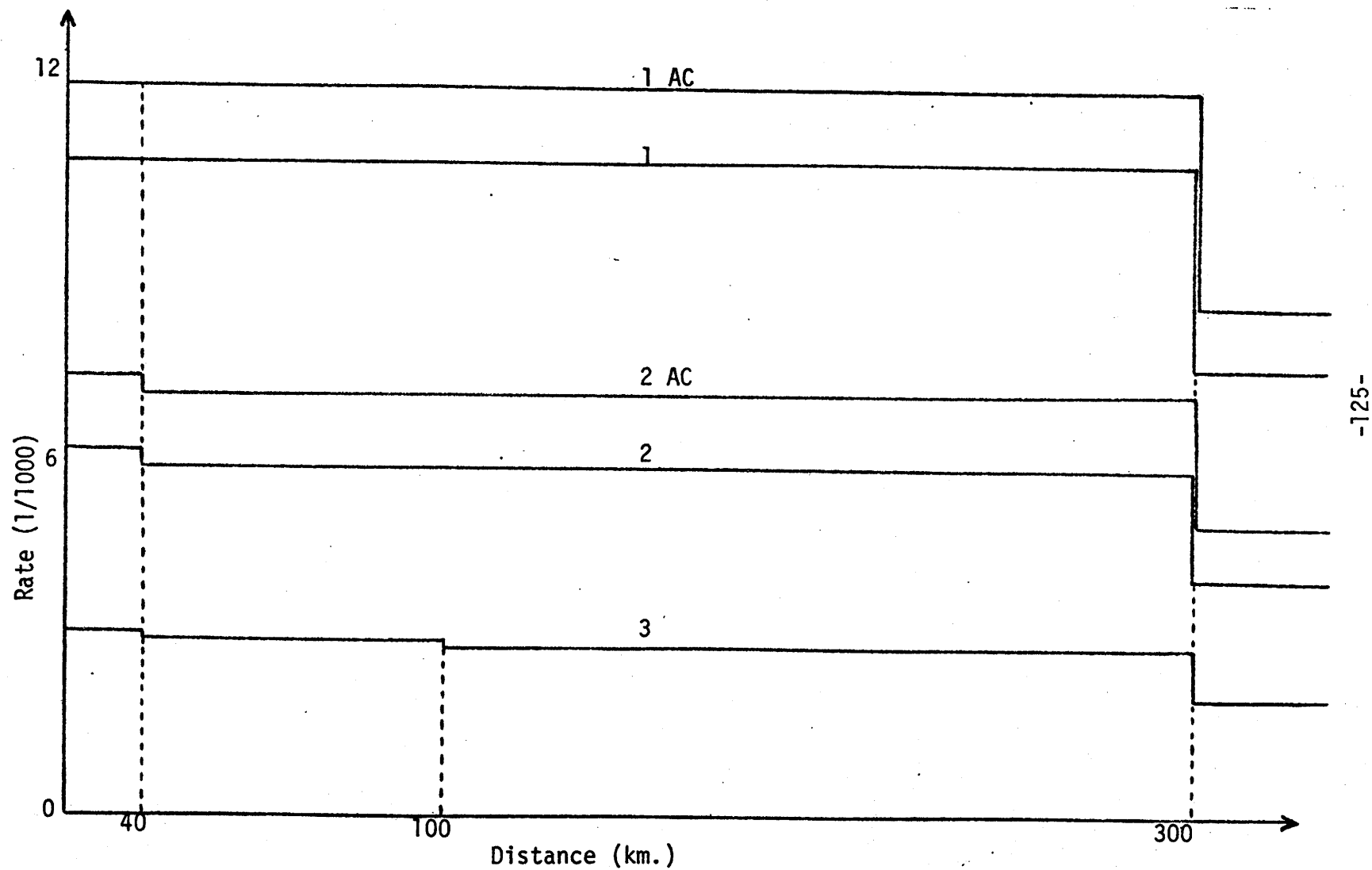
The theoretical framework is:

$$\text{LOSS/DAMAGE [COMMODITY } k] = f [\text{COMMODITY ATTRIBUTES, FLOW OF } k, \\ \text{TT, SHIPMENT SIZE, LINK}]$$

where: TT = transit time

COMMODITY ATTRIBUTES = { density
value per pound
shelf life
environment requirements (e.g. temperature control)...

Figure XXIX. Passenger Tariffs. (milliemes/pass. km.)



AC = airconditioned
1,2,3 = classes

All possible explanatory variables have been included in the model. Regression analysis is the only theoretical framework, provided data are sufficient. Three main models can be used.

$$\text{linear: } L/D = \alpha_0 + \sum_{i=1}^N \alpha_i X_i$$

$$\text{semi-log: } L/D = \exp. \left[\alpha_0 + \sum_{i=1}^N \alpha_i X_i \right]$$

$$\text{product form: } L/D = \alpha_0 \prod_{i=1}^N X_i^{\alpha_i}$$

If the lack of data does not allow to perform a regression analysis, average observed amount of loss and damage will be used, without any explanatory relationship.

The corresponding cost which should be used is the fraction of the value of lost goods which is not reimbursed through claim-processing. If information about it is not available, or if the length of claim processing is too large, then the mere value of the goods considered will be used.

e. Stock-out costs: reliability

A complete analysis of the problem of reliability can be found in Chapter III, section 4. The ideal framework would be the firm level, since different typical situations can occur. The best measure of

reliability, from the shipper's point of view seems to be:

% late : as defined in section III-4.

The parameter N, which is the number of days after the mean or median which is considered, can vary, according to the commodity and the firm. Aggregation can be performed at a commodity level.

Then a stock-out cost must be obtained. It will be assumed to be independent of the duration of stock out and of the number of items concerned. Averages will simply be used over these two variables.

For industrial firms, when the commodity is an input, a percentage of the average output not produced because of a lack of input, should be used.

For retailers and wholesalers the contributions of the products which have not been sold because of unreliability should be used. If data availability does not allow such a detailed analysis, the standard deviation can be used, with a theoretical cost of one hour of unreliability as determined through surveys among shippers. Very broad averages can be used and tested through trial-runs of the model.

Capital carrying costs of safety stocks, which are probably more easily available could be used as proxy variables, since one can sensibly assume that they are directly connected to reliability.

f. Rolling-stock requirements.

Description of the rolling-stock: it will be divided into several categories. Cars will be characterized by an index i , i being an integer between 1 and n , if n is the total number of car types. Similarly locomotives will be characterized by their horsepowers and some other characteristics (diesel or electric, specific function...) An index j will be used for locomotive-type.

For each car type i , two main characteristics will be used.

- the age distribution

$$p_i = p_i[\text{age}]$$

p_i = percentage of cars of type i and age between $[\text{age}]$ and $[\text{age}] + d[\text{age}]$.

- for each age and car type the availability distribution:

$$t_i = t_i[\text{age}]$$

t_i = average percentage of time a car is out of order, for any reason.

This can be obtained from maintenance records.

The function t_i contains explicitly or implicitly several explanatory variables:

$$t_i = t_i[\text{age, mileage, conditions of utilization, maintenance quality}]$$

Typical data formats are given on Figure XXX.

Consequently for car-type i , the average percentage of cars out of order is:

$$R_i = \int p_i[\text{age}] t_i[\text{age}] d[\text{age}]$$

therefore if N_i is the total number of cars of type i , car availability is:

$$n_i = N_i[1 - R_i]$$

Inversely R_i can be considered as a reserve factor. If n_i vehicles must be available then the total number of vehicles must be:

$$N_i = \frac{n_i}{1 - R_i} \approx n_i[1 + R_i]$$

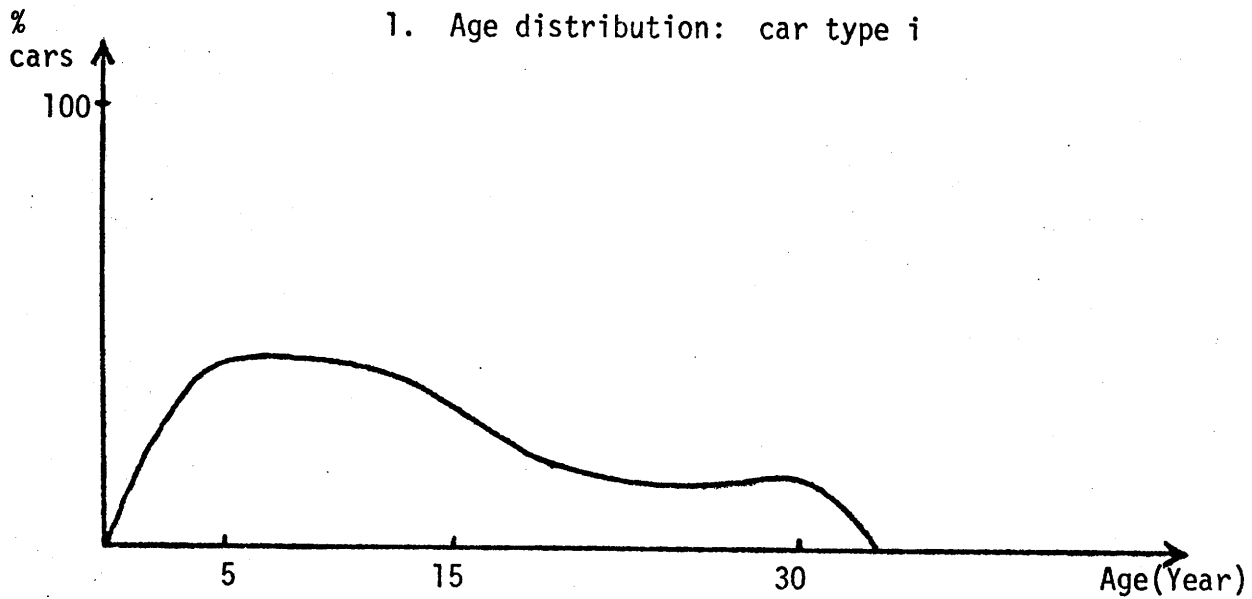
The same framework can be used for locomotives.

The constraint of vehicle requirement can be expressed in several ways according to the way fleet is allocated.

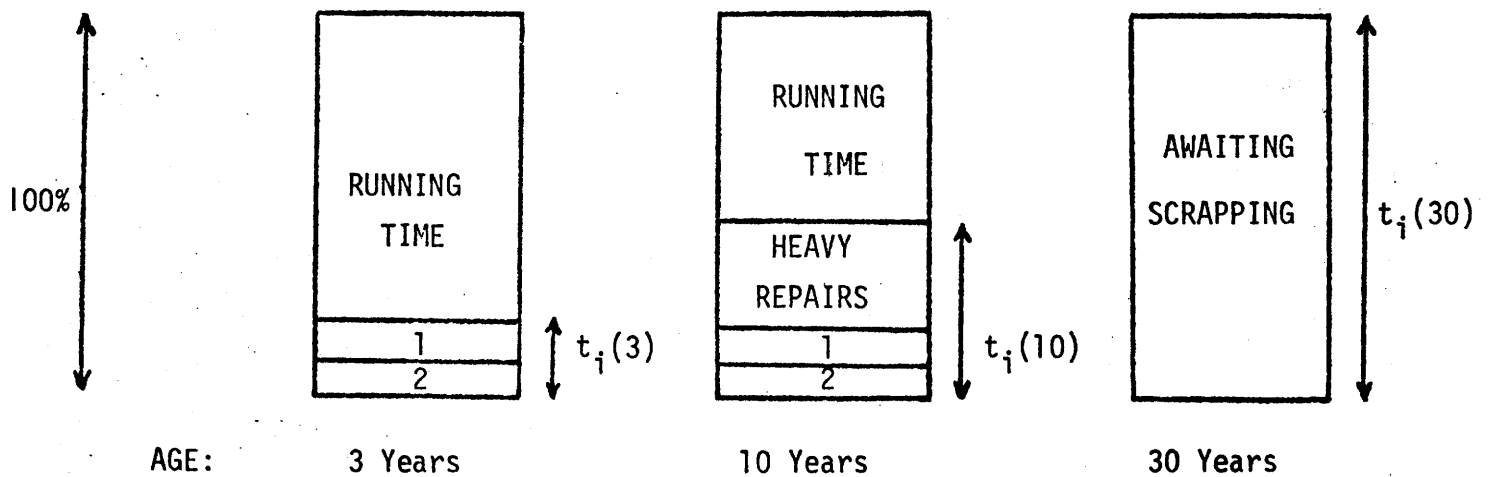
- when rolling stock is allocated to a link, expressing the number of car-trips/day yields:

$$\frac{24 \times n_i}{BT_i} = \text{FREQU.} \times \text{NCAR}_i \Rightarrow n_i = \frac{BT_i}{24} \times \text{FREQU.} \times \text{NCAR}_i$$

FIGURE XXX.



2. Yearly Records of Maintenance for Car type i
(Example)



where: n_i = number of available cars i required
 BT_i = block-time for a complete cycle of car i
 (round-trip service time and buffer-period)
 $FREQU$ = frequency in trains/day
 $NCAR_i$ = number of cars of type i per train (average).

- since rolling stock is certainly allocated at a higher level (whole network or part of it), constraints of the following type must hold, in total car miles for example.

$$\sum_{\text{links}} DIS \times FREQU \times NCAR_i \times DAYS = N_i \times AVDIS_i$$

where: DIS = link length
 $DAYS$ = number of operating days during the period considered
 N_i = total number of cars i
 $AVDIS_i$ = average distance made by a type i car per period.

The summation must be made on any subset of the network to which a portion of the fleet is allocated.

Remark: Since the time framework is a year, broad gross units must be used, such as car-miles. It does not provide any information about peak-periods; those condition global requirements on the whole fleet. A simulation of operations, at a smaller time scale would allow to check whether vehicle availability meets needs at any given instant. This drawback is inherent to the use of average data over a year.

Demand Constraint: The basic relationship expresses the fact that the average daily flow must be handled on the link considered.

$$\text{FREQU} \sum_{j=1}^J \text{NCAR}_j \times \text{CAP}_j \times \text{LF}_j = F$$

where: J = number of car-types
 CAP_j = capacity of cars of type j
 LF_j = load factor of cars of type j ($0 \leq \text{LF}_j \leq 1$)
 F = average daily flow on the link considered

Besides, if C_k is defined as the subset of car-types, that can carry commodity k then:

$$\text{FREQU} \sum_{i \in C_k} \text{NCAR}_i \times \text{CAP}_i \geq F_k$$

$$\text{with } \sum_{k=1}^K F_k = F$$

where: F_k = daily flow of commodity k on the link
 K = number of commodities.

Locomotive requirements: It can be expressed by saying that the power to weight ratio of the average train must exceed a standard level ρ_{MIN} .
Then:

$$\rho = \frac{n\ell \times H}{TW} \geq \rho_{\text{MIN}}$$

where: $n\ell$ = number of locomotives per train

H = horsepower

TW = total train weight

(ii) General Structure

The basic structure of any model can be summarized by three major components, as described in Chapter II:

- inputs
- internal computations
- outputs.

We shall review the characteristics of these.

1. Inputs and data requirements.

The inputs of the unimodal models will be related to three main areas:

- (a) links: physical description, and operational characteristics
- (b) vehicles: physical description,
- (c) commodities: physical attributes, transportation requirements.

Besides, the outputs of the submodels described above will be inputs of the specific internal computations of the unimodal models.

a. Link description: the first set of inputs will describe the link, as regards both its physical and operational characteristics.

- physical characteristics:

- length: DIS
- maximum ruling grade: G_{MAX}

- average grade: AG
- maximum speed due to physical characteristics: SP_{MAX}
- maximum load per axle: WPA_{MAX}
- number of tracks: 1 or 2
- signal system category: it will be represented by typical delays due to signalling, as mentioned in the trip-time submodel. If there are S types of signal systems, the index s will represent the signal system type of the link:

$$1 \leq s \leq S$$

Corresponding average waiting times, (WT_s) will be stored separately.

- switching system category: the approach will be the same.

The corresponding index will be:

$$1 \leq h \leq H$$

where: H = total number of types of switching systems.

The corresponding delay time will be: (ST_h) .

As described in the trip-time submodel, the average delay per meet on the link will be:

$K = WT_s + ST_h$

- capacity of the link: There are several ways of computing link capacities, either actual, optimal or theoretical. Methods investigated by E.R [18] can be used to determine the maximum number of trains per day on a given link.

A formula, traditionally used by E.R. is:

$$C_1 = \frac{1440}{t + t_1} \times K \quad (\text{single track})$$

where: C_1 = maximum number of trains per day in both directions.

t = longest running time of a train between two crossing sections (in minutes)

t_1 = time for setting and cancelling routes (in minutes)

K = efficiency factor (usually between 0.7 and 0.9).

K depends on:

- the relative frequencies of trains with different speeds
- traffic composition and priorities
- availability of terminal capacity
- availability of motive power
- time required for track maintenance and renewal.

$$C_2 = 2 \times \frac{1440}{t + t_1 + t_2} \times K \quad (\text{double track})$$

where:

C_2 = maximum number of trains in both directions per day

t = scheduled time between trains

t_1 = same definition as above

t_2 = longest track occupation and time between any consecutive interlocking stations or station yards.

[for yards] - P.MAKE CURVE type: yards will be classified according to a set of typical P.MAKE curves. A corresponding index will be defined:

$$1 \leq p \leq \underline{P}$$

where: \underline{P} = total number of P.MAKE curves.

● Operational policy: The operational policy, in terms of average data will be inputs of the link considered.

The main variables are:

- frequency: FREQU. in trains per day
- operating speed: SPEED
- train composition: $[NCAR_j]$; $1 \leq j \leq J$
 $NCAR_j$ = number of cars of type j per train
- number of locomotives per train: n_ℓ
- crew size: CS (number of men).

There are several constraints which must hold for these variables, in addition to those mentioned in the rolling-stock requirement submodel.

$$SP_{MIN}[LOCO] \leq SPEED \leq SP_{MAX}[LINK]$$

where: $SP_{MIN}[LOCO]$ = minimum speed under which engines are overheating.

$$FREQU_{MIN} \leq FREQU \leq C$$

where: C = capacity

FREQU_{MIN} = service requirement

$$\boxed{\text{NCAR}_{j\text{MIN}} \leq \text{NCAR}_j \leq \text{NCAR}_{j\text{MAX}}} \quad \text{for all } j.$$

where: $\text{NCAR}_{j\text{MIN}}$ and $\text{NCAR}_{j\text{MAX}}$ express constraints upon train length and composition.

$$\boxed{\text{WPA}_j \leq \text{WPA}_{\text{MAX}}} \quad \text{for all } j.$$

where: $\text{WPA}_j = \frac{W_j + \text{CAP}_j \times \text{LF}_j}{N_j}$

N_j = number of axles of cars of type j

WPA_j = weight per axle of cars of type j

W_j = weight of cars of type j

CAP_j = capacity of cars of type j

LF_j = load factor of cars of type j

$$\boxed{\text{TW} \leq W_{\text{MAX}}[G_{\text{MAX}}]}$$

where: TW = total train weight

$$\text{TW} = n\ell W\ell + \sum_{j=1}^J \text{NCAR}_j [W_j + \text{CAP}_j \times \text{LF}_j]$$

$W\ell$ = weight of one locomotive

J = number of car types

W_{MAX} = maximum weight imposed by the brake system of cars,

as a function of the maximum ruling grade.

b. Vehicle characteristics.

- for each car type j: $1 \leq j \leq J$
 - feasible commodities: subset of the indices of commodities which can be carried by type j cars, i.e. the indices k, $1 \leq k \leq K$, such that j belongs to C_k (defined before).
 - capacity: CAP_j
 - weight: W_j
 - number of axles: N_j
 - air resistance coefficient: K_j
 - initial cost: IC_j
 - age distribution: $p_j = p_j[\text{age}]$
 - availability distribution: $t_j = t_j[\text{age}]$ (as defined in the rolling-stock requirement submodel)
 - average life-time: AL_j
- for each locomotive type i: $1 \leq i \leq I$
 - horsepower: H_i
 - weight: W_{ℓ_i}
 - oil consumption ratio: OR_i (gallons of fuel per gallon of oil)
 - fuel consumption per horsepower hour: $GPHPH_i$
 - number of axles: N_{ℓ_i}
 - air resistance coefficient: K_{ℓ_i} (can depend on the position

of the locomotive in the train).

- initial cost: IC_{ℓ_i}
- age distribution: $p_{\ell_i} = p_{\ell_i}[\text{age}]$
- availability distribution: $t_{\ell_i} = t_{\ell_i}[\text{age}]$
- average life time: AL_{ℓ_i}

c. Attributes of commodity k: $1 \leq k \leq K$

The total number of commodities is user-specified. The main characteristics of commodities which are needed are:

- density
- value per weight unit
- shelf-life
- environment requirements: special handling, temperature control.

Passengers will be one or several commodities, for which the only requirement will be to be carried by a specific subset of car-types, i.e. the various types of passenger cars.

d. Cost elements.

Every price included within the model will be broken into three components:

$$P = P_1 + P_2 + P_3$$

P_1 = foreign exchange component

P_2 = economic value added domestically (e.g., for fuel it can be refining and transport costs (for crude oil))

P_3 = financial value added domestically (e.g., taxes, import duties)

Obviously some of these components can be equal to zero. The main cost elements involved will be:

- fuel cost per gallon: FP
- oil cost per gallon: OP
- crew member cost per train hour: CP
- wage-rate of category m of employees: WR_m (per hour)
- cost of spare parts of car type j: SPP_j . An aggregate composite price will be used.
- cost of other resources used in maintenance of car type j: ORP_j
Similarly an aggregate measure will be used.
- cost of spare parts for type i locomotives: SPP_i
- cost of other resources used in maintenance of type i locomotives:
 ORP_i
- cost of spare parts used in track maintenance: SPP
- cost of materials used in track maintenance: MP

For the last four items, a composite price will be used, which should allow to evaluate the cost of a given composite volume of them. This will obviously imply a broad aggregation on spare parts, or materials.

All data related to maintenance will be dealt with in the following

section, since they require additional computational treatments.

2. Internal computations and final functional formulation.

Only new variables will be defined in this section.

Fuel cost FC

Given operational and physical conditions, the fuel consumption model will be able to produce the amount of fuel consumed for a given trip: FUEL.

then per trip:

$$FC = FUEL \times FP$$

where: $FP = FP_1 + FP_2 + FP_3$ (as defined before)

The number of trips per year on a link is:

$$FREQU \times DAYS$$

where: DAYS = number of operating days per year.

Oil cost OC

$$OC = \frac{FUEL}{OR} \times OP$$

where: $OP = OP_1 + OP_2 + OP_3$

In the previous section, OR is described as an input for each locomotive type, implicitly such a relationship exists and could be estimated:

for type i: $OR_i = f_i[\text{age, maintenance}]$.

Crew cost

CC

The easiest unit for crew cost is certainly the cost per crew member per train hour, which has been defined as: CP

For a period of "DAYS" days:

$$NTH = FREQU \times DAYS \times TT$$

where: NTH = number of train hours

TT = trip time by the trip time model (in hours)

then:

$$CC = CS \times CP \times NTH$$

Car depreciation cost

CDC_j for type j car

per yard per car:

$$CDC_j = CRF_j \times IC_j$$

where:

$$IC_j = IC_{j_1} + IC_{j_2} + IC_{j_3}$$

CRF_j = capital recovery factor

$$CRF_j = \frac{r(1+r)^{AL_j}}{(1+r)^{AL_j} - 1}$$

r = interest rate used in amortizing investments in rolling stock.

Car maintenance cost

CMC_j for type j car

Within a reasonably small range of, on one hand, the level of output, and, on the other hand, the underlying technology, a production function approach can be used involving three categories of inputs: labor, spare parts and other resources, which is the difference between total input and the first two ones. Two components can be defined:

- a fixed cost per period of time and per car of type j: FCMC_j

$$\bullet \text{ labor: } \sum_{m=1}^M FMH_{jm} \times WR_m = FLC_j$$

where: FMH_{jm} = number of man-hours of employees of category m, for type j car.

M = number of categories considered within the labor force

WR_m = wage rate of category m (per hour)

FLC_j = fixed labor cost.

$$\bullet \text{ spare parts: } FSP_j \times SPP_j = FSPC_j$$

where: FSP_j = volume of composite spare parts needed

SPP_j = SPP_{j1} + SPP_{j2} + SPP_{j3} = spare part cost

FSPC_j = fixed spare part cost.

$$\bullet \text{ other resources consumed: } FOR_j \times ORP_j = FORC_j$$

where: FOR_j = volume of other resources consumed

$$ORP_j = ORP_{j_1} + ORP_{j_2} + ORP_{j_3}$$

$FORC_j$ = fixed cost for other resources

then per year and car:

$$FCMC_j = FLC_j + FSPC_j + FORC_j$$

Implicitly or hopefully explicitly, FMH_{jm} , FSP_j and FOR_j are functions of:

- age
- past maintenance
- past conditions of utilization.

These three variables could be summarized in the notion of serviceable age: a corresponding index can be built for each type of car.

- a variable maintenance cost per car-mile: VMC_j

Using a V (for variable) instead of a F for fixed, the same notations as before will be used:

per car mile:

$$VMC_j = VLC_j + VSPC_j + VORC_j$$

with again: $VMH_{jm} = f_j[\text{serviceable age}]$

$VSP_j = f_j[\text{serviceable age}]$

$VOR_j = f_j[\text{serviceable age}]$

For type j car, on a given link and for a period of "DAYS" days the number of car-miles is:

$$NCM_j = \text{FREQU} \times NCAR_j \times \text{DIS} \times \text{DAYS}$$

Locomotive maintenance cost LMC_i for type i

Using a L (for locomotive) instead of a C (for car), the same approach and subsequent formulation will be used:

per year and locomotive:

$$FLMC_i = FLC_i + FSPC_i + FORC_i$$

where: $FLMC_i$ = fixed maintenance cost

per locomotive mile:

$$VLMC_i = VLC_i + VSPC_i + VORC_i$$

where: $VLMC_i$ = variable maintenance cost.

Here again a serviceable age index can be defined and used in the same way as above.

For a type i locomotive the number of locomotive miles, on a given link, for a given period of time (DAYS) is:

$$NLM_i = \text{FREQU} \times n_{\ell_i} \times \text{DIS} \times \text{DAYS}$$

where: $n_{l,i}$ = number of locomotives "i" per train.

Remark concerning cost-allocation: Rolling stock depreciation costs and the fixed components of rolling stock maintenance costs are not directly related to a link. Therefore an allocation process must take place. As often as possible, consistency with the allocation process of E.R should be respected. Several units can be used:

- TON-MILES; PASSENGER-MILES
- CAR-MILES/LOCO-MILES
- CAR-DAYS/LOCO-DAYS.

All these statistics are easily available as functions of the main variables defined before. Gross ton-miles seem to be adequate units in many cases.

$$NTM = DAYS \times DIS \times FREQU \times \sum_{j=1}^J [NCAR_j \times CAP_j \times LF_j]$$

where: NTM = number of ton-miles.

If passengers are considered as one, or several commodities, it is easy to find the equivalent of passenger miles in ton miles.

Maintenance of way cost	TMC
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Here again, the basic framework will be a production function.
Maintenance costs will be broken into two parts:

- a fixed component per period of time and per mile of track.

Here again we shall have to consider:

- fixed labor cost:

$$\sum_{m=1}^M FMH_m \times WR_m = FLC$$

where: FMH_m = number of man-hours of employees of category m

FLC = fixed labor cost.

- spare parts:

$$FSP \times SPP = FSPC$$

where: FSP = volume of spare parts needed

$SPP = SPP_1 + SPP_2 + SPP_3$ = spare part cost

$FSPC$ = fixed spare part cost.

- materials:

$$FM \times MP = FMC$$

where: FM = volume of materials needed

MP = materials cost

FMC = fixed material cost.

Then per period of time and mile of track:

$FTMC = FLC + FSPC + FMC$

- a variable component per ton-mile and per mile of track.

This term is the expression of track deterioration, as a function of traffic. The main components, using the same notations as before will be:

VMH_m , VSP, VM.

(variable amounts of man-hours, spare parts and materials)

The main explanatory variables are:

- frequency
- axle loading
- speed
- train length.

Therefore the actual relationships to consider will be:

$VMH_m = f[\text{axle loading, speed, train length, frequency}]$

$VSP = f[\text{axle loading, speed, train length, frequency}]$

$VM = f[\text{axle loading, speed, train length, frequency}]$

where: VMH_m = number of man-hours of category m

VSP = composite volume of spare parts

VM = composite volume of materials.

In this case, actual ton-miles (including locomotives and cars) should be considered:

DAYS x FREQU x DIS x TW; where TW = total weight of the average train.

Regression analysis should be used for the functional relationships mentioned above, if engineering formulae are not available. Then with the same notations, per actual ton-mile and per mile of track:

$$VTMC = VLC + VSPC + VMC$$

where: VTMC = variable maintenance cost per ton-mile, and mile of track.

Basic cost

BASE

Once allocation has been done:

$$BASE = \text{FUEL COST} + \text{OILCOST} + \text{CREW-COST} + \text{ROLLING-STOCK MAINTENANCE COST} + \text{MAINTENANCE OF WAY COST}$$

Traffic cost

TC

Traffic costs (advertising, management, ticketing, billing and so on...) are modelled as proportional to basic costs.

$$TC = \alpha_1 \times BASE$$

Overhead cost OVC

They will be modelled in the same way.

$$OVC = \alpha_2 \times \text{BASE}$$

The two proportionality constants α_1 and α_2 will reflect organizational efficiency of the E.R. To this extent they can include, explicitly if possible, variables linked with organizational features. But as it has been pointed before, modelling this area seems to be hardly feasible.

N.B. Once link allocation is done, costs will be allocated to commodities, according to the corresponding tonnage on the link, during the period considered.

3. Outputs and conclusion.

The outputs of this part of unimodal models will be synthesized in the generalized cost function. They are the first set of outputs as described in chapter two. They are mainly:

- operator's costs: they have been described in section two above.
- user's costs: trip-time, rates, loss and damage sub-models allow to compute total user's costs.

The combination of these costs, thanks to the permeability constant described in Chapter II produces the generalized cost which will be used

in the equilibration procedure.

Now, the second step of unimodal study, as described in Chapter II, goes beyond the scope of this thesis.

The unimodal model can be used in the quantifying of a whole set of policy impacts. A sample of them, given qualitatively is shown on Figure XXXI.

Figure XXXI
EVALUATING ALTERNATIVES

ALTERNATIVES	SERVICE VARIABLES						OPERATING COST			CAPITAL COST				
	Reliability:		Trip Time:		Loss & Equip. Damage Supply		Road	Yard	Other	Road	Yard	Loco	Car	Other
I. OPERATING CHANGES														
a. shorter trains	+	+	+	+	(+)	+	-	-	-	-	-	±	+	0
b. through blocking	0	+	0	+	(+)	+	0	+	-	0	(+)	0	+	0
c. schedule adherence	(+)	0	(+)	0	±	0	±	0	-	0	0	-	0	±
d. more power	0	+	0	±	0	+	0	±	±	0	±	(+)	(+)	0
e. car control systems	0	+	0	±	0	+	0	±	-	0	0	0	±	-
f. stricter inspections	+	±	(+)	±	+	±	0	-	±	0	(-)	0	0	0
II. CAPITAL IMPROVEMENTS														
a. improved cars	+	(+)	(+)	(+)	+	+	(+)	(+)	(+)	0	0	0	-	+
b. improved locomotives	+	(+)	0	+	(+)	0	+	0	0	0	0	-	0	±
c. more yard capacity	0	+	0	+	(+)	+	0	±	0	0	-	0	+	0
d. more road capacity	+	0	+	0	0	0	±	0	0	-	0	+	0	0
III. INSTITUTIONAL/ COMMERCIAL CHANGES														
a. reg. traffic input	+	+	0	(+)	0	+	±	+	0	0	+	0	+	(+)
b. work rule changes	+	+	(+)	+	0	+	+	+	(+)	0	0	±	+	+

KEY:
 + Improved
 ± Equivocal
 - Degraded
 () Weak Effect
 0 No Effect

CHAPTER V

MODE SPECIFIC STUDY: INLAND WATERWAYS.

Introduction: presentation of Egyptian inland waterway transportations.*

Egypt has a natural axis, the Nile, along which population is very dense. This situation is very favorable to a mode of transportation which is characterized by low freight rates, due to high capacity and low costs.

The waterway network mainly includes the Nile, a canal network, the chief elements of which are the Nobarria and Beheiri canal, and lake Nasser from Aswan to the border with Sudan. These are "class I" waterways and have a total length of 1495 km.. In addition, "class II" waterways have a length of 1849 km.. The latter category is characterized by a minor traffic and poor navigation conditions. On most waterways, priority is given to irrigation demands, but transportation activities do not seem to suffer too much from this situation. The Roads and Waterways authority is in charge of building, maintaining and improving waterway infrastructures. Two public sector companies, the General Nile Company for River Transport and the General Nile Company for Waterways Transport account for more than 40% of the total capacity. With the Sugar Company (which belongs to the public sector, too), they handle more than 70% of the whole waterway traffic.

*Most statistical information comes from the Egypt National Transport study interim report of 1977. (18)

Estimations of this range from 3.34 to 6.08 million tons, due to the great uncertainty which characterizes operations of sailing boats, which represent 46.5% of total capacity (1973). The latter was estimated to be 604,907 tons.

Capacity does not seem to be a problem at the moment, because of a relatively low level of demand. The main stumbling block is the loaded draft. It ranges from 1.2 to 1.8 m. for the Nile which is uneconomical and increases transport costs considerably.* Another one is the poor level of performance of port facilities. Loading and unloading equipments have a very low rate of utilization and a highly questionable efficiency. Reliability in loading and unloading times is very bad. (For a unit of a capacity of 800 tons, on the average four days are spent per month in operations of loading and unloading.)

As a conclusion, waterway transportation in Egypt have a very good potential situation within the transport sector, because of favorable geographical conditions. An adequate investment policy is very likely to improve dramatically the market share of this mode, which is obviously underused.

1. Issues in investment policy: a qualitative approach of its impacts upon costs and flows.

*It can result in a loss of 20% in loading capacity.

(i) The Nile and canals.

As regards the Nile, the impact of the High Dam seems to have been negative. The water seems to have lost an important part of its tractive force due to its weight and velocity. Sand deposits are the main consequences of this phenomenon. Besides there has been little gain in the maximum loaded draft period. The latter ranges from 1.2 to 1.8 m., according to the time of the year. The main issue in investment policy as regards the Nile is therefore its regulation. A permanent and safe channel, with a depth of about 2.0 m. is the basis for calculating the most economical freight rates. There is no problem of width.

As regards "class I" canals, again, the main problem seems to be the loaded draft. It is 1.5 m. for the Beheiri canal. This is definitely an important factor of increase in costs. Besides some sections of the canal are not wide enough to allow efficient and safe maneuvers.

At last, a great issue seems to be bank protection. This is a problem impacting both maintenance (through deterioration) and operations.

As a conclusion, the main issue, as regards its impacts upon costs and flows is definitely the loaded draft, which has a direct influence upon feasible load factors.

(ii) Locks

The capacity of a waterway is determined by its weakest component.

In most cases locks set the upper bound, because of inadequate dimensions (length, width, loaded draft).^{*} Therefore locks are a key issue in investment policy. Besides, the way lock-gates are operated, either electronically or manually has a direct impact upon operations, through waiting time. All these elements determine the capacity of the lock considered, in terms of tons per unit of time.

(iii) Bridges.

There are three types of bridges on canals:

- lift bridges
- swinging bridges
- regular bridges.

The two elements that directly impact transportation operations are their clear height and their clear span. The following standards apply to fixed river bridges, for example:

clear height: 6 m.

clear span: 25 m.

A clear height of 4 m. seems to be sufficient for commercial vessels currently operating on the Nile as well as on most waterways. Except in a few cases, bridges do not seem to be a major constraint to waterway transportations.

^{*}For example, the loaded draft of the Nobaria and Beheiri canal is limited by one lock.

(iv) Shipyards.

Shipyards have a key role to play in waterway transportation. On one hand as regards ship-building, on the other hand for maintenance operations. The efficiency of shipyards directly conditions fleet availability through repair and waiting periods. They can reach 9.8 days per month for the two major companies which have the best facilities in this field. This is definitely a major constraint upon operations.

(v) Ports.

Terminal operations are a key component of the waterway transportation system. Waiting, loading and unloading times can reach 6.4 days per month, which is an important restriction upon capacity. Therefore terminal infrastructures are a priority, if waterway transportations, which are characterized besides by large travel times, must compete efficiently with other modes. They include both quayside facilities and loading and unloading equipments. Besides, links between ports and plants are particularly bad.

(vi) Fleet.

Public companies mostly run "units", consisting of a self-powered barge and a lighter, with a total capacity of around 320 tons. The main issues as regards fleet investments are:

- Capacity: units could be replaced either by self powered barges, with a capacity of 500 tons, thus minimizing handling time and new investments necessary to meet loaded draft constraints; or "European type" barges, with a capacity of 1,350 tons, to make the most of economies of scale. In such a case they could be used at their full capacity only if works were made to increase the loaded draft (it would require 2.5 m.).
- Containerization: Although rail and road seem to have a marked advantage in this field, because of shorter trip times and easier handling operations, container transportation cannot be discarded for short distances. The subsequent problem would be terminal facilities.
- Motorization of sailing boats: They account for 240,000 tons, approximately 46.5% of the total capacity, but handle only about 10% of the transport flows of the three major companies, mainly operating on short distances (of around 50 km.). Individual capacity ranges from 50 to 100 tons. Self powered craft would have better line-haul performance. Major problems would arise from shipyard capacity, maintenance of engines, fleet ownership, important handling times which would partly offset line-haul gains.
- At last the relationship between maintenance and investments remains a key issue, all the more so as one considers shipyard capacity and subsequent average idle times. Therefore, fleet availability is much more impacted by the age of its components and their subsequent

maintenance needs.

2. Operating regulations; maintenance and operations: a qualitative approach of their impacts upon flows and costs.

(i) Operating regulations.

- service regulations: there do not seem to be very binding constraints upon the services, even when provided by the two public sector companies.
- equipment regulations: the same comment can be done as above.
- labor regulations: very little information is available as regards specific labor regulations in the waterway transportation industry. Anyway, there is definitely a difference between public sector companies (River Transport, Water Transport, Sugar Company) and sailing boat operators, who seem to undergo a very weak pressure from the government as regards many regulations.
- environmental regulations: inland navigation is a very favorable means of transport as regards physical nuisances. The main source of pollution is waste oil. For example, it is estimated that about 1.5 tons per vessel are lost in the Rhine River. There is no reason why such an order of magnitude is not to be found in Egypt. The solution would

be the construction of a waste oil collection station. Operating regulations would have to be set, such as the periodicity of oil cleaning. Besides noise level regulations would be a second area of possible intervention of the Egyptian Authorities. At the moment the regulatory framework is very permissive.

(ii) Operational options

● Most physical constraints upon operational characteristics such as load factor, speed, frequency have been mentioned above. Besides the standard units seem to consist of a self-powered barge pushing a lighter, or a self-powered barge alone. The operating speed seems to be around 11 km./k/ Therefore there is no attempt to optimize the operations by choosing the optimal combination of horse-power and loaded capacity. Anyway lock capacity restricts this search considerably, as well as fleet availability. Under present conditions, and assuming 30% of empty trips the theoretical capacity of the 211 units owned by the two public sector companies was estimated to be 886 million t.km (1975). The actual performance was 863 million t.km., i.e. 98% of the estimated capacity. The main stumbling block is not the physical capacity of the fleet, but an actual travel time of 9.5 days per month. According to the shipping companies the average monthly lay-days are:

handling idleness:	2.4 days
loading time:	2.0 days
unloading time:	2.0 days
maintenance:	4.6 days
maintenance waste time:	5.2 days

waiting at locks and bridges:	4.3 days
total:	20.5 days

Gains of 50% in the theoretical capacity of the 211 units are possible, according to the Interim report of 1977 (mentioned before):

- 7% would result from a utilization of a constant loading draft of 1.8
 - 43% would result from higher travel performances due to gains in handling, maintenance and waiting-time at bridges.
- Another important issue in operations as well as in investment is the lighting of waterways for night-trips. This would imply high investment and maintenance costs, and additional operating costs connected with locks, handling facilities and accommodations for two crews. Besides most European studies have led to the conclusion that radar-navigation was much preferable. Anyway an increase in daily operating hours, which does not imply any investment seems to be an interesting alternative, if fleet utilization has to be improved.
- Lock operations: when they are operated electronically the total lock-time can be estimated to one hour. It is comparable to European standards. Therefore, since the present capacity of locks seems to be sufficient, lock operations are quite satisfactory. Waiting-time varies with the average flow on the waterway considered, according to queueing theory formulae.

- Maintenance: it implies mainly the routine and periodic maintenance of locks, bank protection, dredging along the Upper Nile and maintenance of ports and landings. Maintenance activities are usually considered as insufficient, particularly as regards ports, which are privately owned, and bank protection, which is normally under the responsibility of the Ministry of Irrigation. Besides dredging is a key-issue, since it conditions the loaded draft, which, as mentioned above is generally too low. Because of its cost*, a constant loaded draft of 1.8 m. on the Nile seems to highly questionable.

- Maintenance of the fleet: mainly due to a lack of shipyard capacity, the maintenance of the fleet is rather poor, resulting in a high repair rate for engines and hulls; consequently fleet availability is impacted, as well as service life, which is shortened. Comparison with standard European costs must take into account a lower cost of labor and a higher cost of material and spare parts. At last information about sailing boats is not available.

3. Market regulations and market structure.

There seems to be two main issues in this field.

- a possible merger of the two public sector companies;
- the tariff structure.

*25 million (m³) at a cost of 12.5 million L.

(i) Market structure.

As mentioned above, there are two public sector companies. The General Nile Company for River Transport and the General Nile Company for Waterways Transport. The question is whether a partial consolidation of their activities should occur, or even whether they must remain under governmental control. This is definitely a key policy issue, all the more so as 70% or more of the total traffic handled within the industry is concerned. In any case, a certain overlapping can be avoided as well as additional costs it generates.

(ii) Tariff structure.

There is no formal regulations as regards tariffs. Each contract is negotiated with the customer in advance. Usually it implies large shipments and long-term orders. The final price depends upon quantity, quality, properties of the goods, and length of the haul. There are many discrepancies as regards the average charge per ton-km., mainly due to the evaluation of total ton-km., involving an artificial equivalent of lay-time which is charged to the customer.

As regards the private sector, very little information is available about tariff structure, as well as costing.

4. Policies which cannot be handled within the unimodal model.

A major stumbling block as regards waterway transportation seems to be a lack of information about the actual situation of the private sector and more specifically of the subset of sailing boats, which account for around 46.5% of the total capacity (1973), around 95% of the private capacity.

On the four main waterways they account for 9.5% of the total traffic. The market share estimations for the private sector range from 14% to 21%.

Consequently there is definitely a problem in modelling the activities of the private sector. A set of simplifying assumptions will have to be done about it.

The relatively simple structure of both the network and the market structure will probably allow to consider policies which apply to these two levels. Most of them have been described in previous sections.

5. Analytical formulation.

(i) Submodels.

The same approach will be used as for railroads. A set of submodels will be used as a preliminary step to the internal computation of actual costs.

a. Fuel consumption.

It does not seem to be worth modelling analytically fuel consumption for barges. The available data, mainly coming from the public sector companies, should allow to have accurate average data corresponding to typical operational conditions, for each type of vessel considered.

For one type, the fuel consumption, GPHPH (in gallons per horsepower-hour) will depend upon several variables:

$$\text{GPHPH} = f[\text{age, past maintenance, operational conditions, load, stream current}]$$

Although analytical relationships will not be expressed, a disaggregate sample of typical fuel consumption rates should be used. Total consumptions can be computed in two ways:

- on a link basis, per trip: given the type of vessel, operational data, and link data.
- on a vessel basis: given daily operating hours, number of operating days per time period, fraction of operating time used in actual move.

- per trip

$\text{FUEL} = \text{GPHPH} \times \text{HP} \times \frac{\text{DIS}}{\text{SPEED}}$

where: FUEL = fuel consumption per trip
 GPHPH = gallons of fuel consumed per horsepower hour
 HP = horsepower of the vessel used on the link
 DIS = length of the link
 SPEED = operating speed on the link.

- per vessel and per period of time ("DAYS" days):

$$\text{FUEL} = \text{HP} \times 8 \times \text{DAYS} \times Y \times \text{GPHPH}$$

where: DAYS = length of the period considered
 8 = number of operating hours per day
 Y = fraction of time used in actual move.

Fleet allocation, on a link basis, allows to compute link data.

b. Trip-time

Here again line-haul segments, defined as parts of the network which do not include locks, will be treated separately from locks themselves.

b.1 line-haul segments:

The trip-time will be broken into five parts:

$$\text{TT} = T_1 + T_2 + T_3 + T_4 + T_5$$

where: TT = OD trip-time
 T_1 = running-time (actual move)
 T_2 = loading and unloading time
 T_3 = handling idleness
 T_4 = waiting time at bridges
 T_5 = waiting time at night, because of the impossibility of night navigation.

● Running-time: there are only 8 operating hours per day on the Egyptian Inland Waterway network. Therefore the total time required to travel a given distance DIS is:

$$t_1 \times 24 + \left(\frac{DIS}{SPEED} - t_1 \right) \times 8 = \frac{DIS}{SPEED} + 16t_1$$

where:

$$t_1 = \text{MAX.} \left\{ N; N \text{ integer}; N \leq \frac{DIS}{SPEED} \times \frac{1}{8} \right\}$$

(t_1) is the number of entire days required, because of the 8 operating hours per day.

$\left(\frac{DIS}{SPEED} \right) - 8t_1$ is the remaining number of hours on the $(t_1+1)^{\text{th}}$ day.

therefore:

$T_1 = \frac{DIS}{SPEED}$
$T_5 = 16t_1$

Now there are several ways of dealing with speed:

- the easiest way is to use average data: for the Egyptian case it would probably be 10 km/h. A distinction can be made according to a movement with the stream or against the stream.

- a second way is to use a speed model, involving both empirical and engineering formulae. The most widely used is that of Howe (21). Another one has been developed by the U.S. Army Corps of Engineers (22).

They are based on the relationship between the effective push of a tow-boat, EP, and the resistance of a barge flotilla, R, when they proceed at a constant speed:

$$EP = R$$

Now: $R = f[H, D, S, W, B, L]$

$$EP = f[HP, D, S].$$

Therefore the relationship can be solved as an equation, the unknown of which would be S. Let us call the solution S*

Then the actual flotilla speed is:

$$SPEED = S^* + (-1)^d S_w$$

where: $d = 0$ for downstream

$d = 1$ for upstream

S_W = stream current
 HP = horsepower of the tow-boat
 D = depth of waterway
 S = speed in still water
 W = width of waterway
 B = breadth of the flotilla
 L = length of the flotilla
 H = draft of the flotilla.

Actual equations are given in appendix B.

Remark: The cargo tonnage is implicitly fixed as a function of L, B and H, then:

$$T = T(L, B, H)$$

where: T = cargo tonnage of the flotilla.

Then the rate of output, in ton-miles per hour is:

$$\text{TMPH} = \text{SPEED} \times T$$

where TMPH is the rate of output.

This gives an engineering production function for the tow.

- loading and unloading time: they can be defined by a loading rate, α , and an unloading rate, β . Implicitly or explicitly the following functional relationships should hold.

$\alpha = f[\text{commodities, port facilities, available labor force}]$

$\beta = f[\text{commodities, port facilities, available labor force}]$.

Then if the cargo tonnage is T:

$$T_2 = [\alpha + \beta] \times T$$

● handling idleness: this time component reflects congestion of port facilities. There are two approaches which can be used:

- the use of average data from observations in the field.
- the analytical formulation of congestion effects; for example the U.S. Army Corps of Engineers models ports delay as an exponential function of total traffic handled (22).

Average delay per barge = $a \exp[bF]$

where: F = total traffic handled in a given period

a,b = parameters.

Data availability will determine the adequate approach.

● waiting-time at bridges: it does not seem to be a major delay.

From a theoretical point of view it depends upon the following variables:

- number of bridges on the link

- frequency of bridge operations
- average delay due to bridge operations.

It will be modelled as a fixed average delay per link and trip.

- total waiting-time: WT

$$WT = T_3 + T_4 + T_5$$

and

$$TT = T_1 + T_2 + WT$$

b.2. Locks.

A more precise analysis of lock operations can produce interesting results, all the more so as, as mentioned before, locks are usually a major bottleneck in inland waterway transportations. In most cases, they condition the very capacity of a whole link.

- Theoretical capacity: the first parameter is the maximum tonnage a lock can handle in one lockage operation, T_{MAX} . Then the average locking time t must be known.

Then assuming 10 operating hours per day, during a period of "DAYS" operating days, the theoretical capacity is:

$$\frac{T_{MAX} \times 10 \times \text{DAYS}}{t}$$

Most waterway transportation studies show that when around 25% of this theoretical capacity is reached, congestion effects begin to be significant.

Of course, T_{MAX} is a function of the physical characteristics of the lock, where as t is a function of its operational characteristics, particularly the way gates work (electrically or manually).

- Locking time: the application of queueing theory to the analysis of lock operations has proved particularly efficient and consistent with actual data. (23)

Basic assumptions: let us assume that the average locking time is $t = \frac{1}{\mu}$; let us call σ its variance. Then let:

$$\rho = \frac{\lambda}{\mu}$$

where λ is the rate of arrival of vessels, per hour for example (then t will be in hours).

ρ is the utilization rate and practically represents the fraction of time during which the lock actually works; ρ is supposed to be smaller or equal to 1, i.e. the system can reach a steady state. (The line cannot

increase to infinity.)

Then queueing theory allows to calculate the average total time spent within the system, i.e. both waiting and actually going through the lock:

$$T_{\ell_1} = \frac{1}{\mu} + \frac{\rho^2 + \lambda^2 \sigma^2}{2\lambda(1-\rho)}$$

The implicit assumption is that the arrival pattern of vessels has a Poisson distribution, which is quite realistic for major waterways. We see that the very variability of locking time, as expressed by σ results in additional delays.

The average length of the waiting line is then given by:

$$L_q = \frac{\rho^2 + \lambda^2 \sigma^2}{2(1-\rho)}$$

Now a main stumbling block is usually the actual availability of σ . When it is not known, the usual assumption is an exponential service time which gives the much simpler result for total locking time:

$$T_{\ell_2} = \frac{1}{\mu(1-\rho)}$$

(in this case: $\sigma = \frac{1}{\mu}$)

The corresponding length of the waiting line is:

$$L_q = \frac{\rho^2}{1-\rho}$$

The formula giving T_{ℓ_2} has been checked satisfactorily in many studies (23).

A more sophisticated analysis can be done about locking time, when priorities are set among the various types of vessels which are likely to use the lock considered.

Let us consider n types of vessels, number 1 is supposed to represent the highest priority (priority decreases when i increases).

Corresponding arrival rates are: $\lambda_i \quad 1 \leq i \leq n$

The average locking times are: $t_i = \frac{1}{\mu_i}$. They can vary according to the type of vessel, because of approach maneuvers for example. The locking time variances are: σ_i . When they are not available the same assumption as before can be made: $\sigma_i = \frac{1}{\mu_i}$.

In such a case, queueing theory shows that the average total locking time is (again including waiting time) for category i :

$$T_{\ell_i} = \frac{1}{\mu_i} + \frac{\sum_{k=1}^n \frac{\lambda_k}{2} \left(\frac{1}{\mu_i^2} + \sigma_k^2 \right)}{(1 - a_{i-1})(1 - a_i)}$$

$$\text{where: } a_i = \sum_{k=1}^i \rho_k = \sum_{k=1}^i \frac{\lambda_k}{\mu_i}$$

Then according to practical situations, and to possible priorities and

disaggregation among vessels, either T_{ℓ_1} , or T_{ℓ_2} or T_{ℓ_i} will be used to compute total locking time.

Remark: queueing theory gives an interesting result related to priority assignment. If a cost of waiting time c_i (in dollars per unit of time for example) can be attributed to each vessel category, then the total cost of waiting can be minimized in this way:

- for each class compute the ratio $\frac{c_i}{\frac{1}{\mu_i}} = \frac{c_i}{t_i}$
- then assign priorities so that the higher the value of this ratio is, the higher the priority is.

If costs of waiting time are all equal, or to minimize total waiting time, then the shortest locking time should correspond to the highest priority.

Further remark and conclusion: Trip-time has been dealt with on a link basis, breaking it into several components and describing each one analytically. Records of average lay-days for a given period and for a given type of vessel would allow to compute various trip time subcomponents, assuming fixed relative weights of handling idleness, handling time, maintenance, maintenance waste time, waiting time at locks and bridges, as given in the Egypt National Transport study (18).

c. Rates.

Data about inland waterway rates are not very precise. Anyway the tariff structure is not clear at all. Provided data requirements could be met, since, according to the National Transport study (18), rates depend upon shipment size, commodity attributes and length of haul, a tariff model could be calibrated. Several forms should be tried, particularly a product form (24), which seems to produce the best results.

For example, the following equation could be used:

$$\text{RATE} = \text{MILES}^{\alpha_1} \times \text{WEIGHT}^{\alpha_2} \times \text{DENSITY}^{\alpha_3} \times \text{VALUE}^{\alpha_4} \times \prod_{i=5}^N e^{\alpha_i X_i} \times e^{\alpha_0}$$

where: RATE = charge in dollars per unit of weight

X_i = dummy variable representing a particular transportation requirement (e.g.: $X_i = 1$ if temperature control is necessary; $X_i = 0$ if not)

$\alpha_i = 0 < i < N$: parameters to be estimated.

In this case elasticities of rates with respect to the various continuous variables involved are supposed to be constant (and equal to their exponents). If it is not the case, for example with respect to mileage, several techniques can be used:

- including a term: $e^{\beta_1 \text{MILES}}$; then the elasticity will be:

$(\alpha_1 + \beta_1 \text{MILES})$, which is a function of MILES.

- using a piecewise approximation by including a term: $e^{\beta_1 M}$

Then M is defined this way:

- $M = 0$ if $\text{MILES} \leq m$; then the elasticity is (α_1)
- $M = \text{Log } \frac{\text{MILES}}{m}$ if $\text{MILES} \geq m$; then the elasticity is $(\alpha_1 + \beta_1)$.

The "cutoff" mileage m , has to be determined as well as the other parameters.

Other variables can be added (as well as suppressed when not significant) involving cross-elasticities for example. In a study concerning barge transportation in the U.S., a term $(\text{RAIL-MILES})^\alpha$ had been significantly included in the equation (24). Rail-mileage was an explanatory variable of barge rates, showing the particular competition between those two modes.

Approximations of actual rates, such as those used for railroads, can be used if such relationships cannot be calibrated.

d. Loss and damage. See the following section.

e. Reliability cost: stock-out costs.

These two submodels have been described in the railroad study. Since they are not mode-specific, the basic framework described in the previous

chapter can be used for inland waterway transportations.

f. Fleet requirement.

The same approach as for railways will be used as regards fleet availability and requirement.

Each vessel type, i , will be characterized by two main data:

- its age distribution: $p_i = p_i[\text{age}]$

where: $p_i = \% \text{ vessels the age of which is between}$
 $[\text{age}] \text{ and } [\text{age}] + \alpha[\text{age}]$

- its monthly average lay days, as a function of the age. (If it is a relevant explanatory variable.)

as a fraction of total time:

- running time: X_{i_1}
- handling time: X_{i_2}
- handling idleness: X_{i_3}
- waiting at locks and bridges: X_{i_4}
- maintenance waste time: X_{i_5}
- maintenance time: X_{i_6}

Of course with: $\sum_{k=1}^6 X_{ik} = 1$

Then the number of vessels of type i actually in operations is:

$$n_i = N_i \int [1 - X_{i_5} - X_{i_6}] p_i d[\text{age}] = N_i [1 - R_i]$$

where: N_i = total number of type i vessels

R_i = reserve factor (as defined in Chapter IV).

Now if fleet requirement is expressed in annual ton-miles, the annual distance travelled is per vessel:

$$D_i = X_{i_1} \times \text{DAYS}_m \times H \times \text{SPEED} \times 12$$

where: DAYS_m = number of operating days per month

H = number of operating hours per day.

Assuming a percentage of e_i empty trips and an available loading capacity of CAP_i due to loaded draft restrictions, annual capacity of type i vessels is:

$$\text{TON-MILES}_{i\text{MAX}} = \frac{(1 - e_i)}{100} \times \text{CAP}_i \times D_i \times N_i$$

Now fleet requirement in ton-miles, can be expressed on any subset of the network, to which a part of the fleet is allocated. The following data will be related to this link or set of links.

- e_i
- CAP_i : connected with the average loaded draft.
- N_i : number of type i vessels assigned to the links considered.
- SPEED: average operating speed.

The very simple structure of the inland waterway network allows a straightforward fleet allocation process.

Seasonal effects should be taken into account as regards:

- demand peaks
- loaded draft: particularly on the Nile.

These are additional constraints upon fleet assignment.

(ii) Inputs and data requirements:

Inputs will be related to links, commodities, ports, locks and vessels. Besides the results of the submodels described above will be used as inputs to the internal computations of the model.

a. Links: here again a link will be defined as a segment of the network which does not include any lock.

The main inputs will be:

- link length
- average current velocity, with the adequate sign (according to its

direction). If seasonal variations are significant they should be mentioned.

- depth: average and minimum. In this case the variations with time of the permissible loaded draft should be provided.
- number of bridges and corresponding characteristics including:
 - clear height
 - clear span
 - frequency of operations
 - duration of operations.
- width: for straight sections and bends
- bank protection: can be classified according to its quality.
- dredging: the rate of sedimentation can be used, or the relationship between volume dredged and actual depth.

b. Commodities: since the model is multi-modal, the same inputs will be used as for railroads. Additional mode-specific inputs will be:

- the set of feasible barge types corresponding to each commodity. There may be a constrained assignment of a fraction of certain commodities to sailing boats for example if they are actually considered as part of modal competition.
- a set of feasible handling facilities will have to be determined as well.

c. Ports: the main relevant characteristics will be:

- capacity
- type of facilities and subsequent feasible commodities
- loading rate
- unloading rate: these two data will summarize the efficiency of port facilities.
- congestion effects: they will be given either by a volume delay curve, as mentioned in the trip-time submodel, or by an average delay per barge.

d. Locks: the inputs will be both physical and operational:

- physical capacity: length, breadth, depth
- crew size
- average locking time and corresponding variance for each type of flotilla (optional: see locking time model above).

e. Flotillas: under this general term, all types of units will be considered, particularly "units" (§), self-powered barges of various types, possibly sailing boats. The main data will be:

- horsepower
- fuel consumption rate
- oil consumption ratio
- length, width, height
- relationship between tonnage and loaded draft
- capacity

- age distribution
- average monthly lay-days as a function of age
- initial cost: hull and engine
- average life-time: for hull and engine
- operating speed, if not given by a speed model
- crew size.

The most binding constraint upon flotilla operations seems to be the loaded draft, which in many cases prevents from using a barge at its full capacity. A way of expressing dimensional constraints (and subsequent loading capacity constraints) is to consider the ratio N:

$$N = \frac{\text{water cross section}}{\text{cross section of the submerged part of the vessel}}$$

A standard of the EEC has set a minimum value of 7 to N.

Remark: Because of the quality of data available about the sailing private fleet, its relatively small market share, the very specific nature of the commodities it carries, and the short average length of haul of its operations, a constrained assignment will probably have to be used. It can be based on a given market share, the type of commodity involved and the length of haul. Actually, operational as well as cost information about sailing boats seems to be hardly available and compatible with any modelling effort.

f. Cost components: at last a set of costs will have to be provided.

Again, any price involved will be broken into its foreign exchange component (index 1), its domestically added economic value (index 2) and its domestically added financial value (index 3).

The costs required are:

- fuel cost
- oil cost
- crew wage rate
- wage rate for each category of labor force
- spare part price for barges of each type
- supply price for barges of each type
- total cost of dredging per m³
- lock costs: operating, maintenance, labor and material cost.

(iii) Internal computations.

The different costs involved will be broken in the following major components:

- fleet costs
- maintenance costs of canals
- maintenance and operating costs of locks.

Remark: most ports are run by private companies. Consequently data about their operating and maintenance costs are not directly relevant to the model. Besides they do not seem to be significant.

a. Fleet costs.

Fuel Cost: As it has been pointed in the previous section there are two ways of computing fuel consumption. Therefore fuel costs will be computed accordingly:

$$FC = FUEL \times FP$$

where: $FP = FP_1 + FP_2 + FP_3 =$ fuel cost per unit

$FC =$ fuel cost (per trip or per vessel)

$FUEL =$ output of the fuel consumption model.

Oil and lubrication cost: Here again a ratio will be used and oil cost will consequently be:

$$OC = \frac{FC}{OR} \times OP$$

where: $OC =$ oil cost (per unit consistent with that of FC)

$OR =$ oil consumption ratio (amount of fuel consumed per unit of oil)

$OP =$ oil cost per unit

$OP = OP_1 + OP_2 + OP_3$

Crew cost: The easiest basic unit is the trip. (It can also be computed per vessel and year).

$$CC = CS \times CWR \times TT$$

where:

CC = crew cost per trip

CS = crew size

CWR = wage-rate per hour

TT = trip time in hours.

Maintenance cost: Maintenance cost will be considered on a vessel basis. It will be broken into two components.

- a fixed amount (per year) of man-hours, spare parts and supplies.
- a variable component per operating hour. Operating time will include everything except maintenance activities and handling idleness. With the notations used before, and if the period considered has "DAYS" operating days, operating time will be:

$$\text{"DAYS"} \times 8 \times [1 - X_{i_3} - X_{i_5} - X_{i_6}]$$

The fixed component will be:

$$FMC_i = FMH_i \times WR + FSP_i \times SPP_i + FS_i \times SP_i$$

where:

(type i flotilla)

FMC_i = fixed maintenance cost per year and vessel

FMH_i = fixed maintenance man-hours

WR = wage rate (average)

FSP_i = amount of spare parts

$SPP_i = SPP_{i1} + SPP_{i2} + SPP_{i3}$ = cost of spare parts
(composite price)

FS_i = amount of various supplies

$SP_i = SP_{i1} + SP_{i2} + SP_{i3}$ = various supplies cost
(composite price).

Remark: Such as for railroads the labor force can be broken into several categories.

With the same notations, the variable component per operating hour is:

$$VMC_i = VMH_i \times WR + VSP_i \times SPP_i + VS_i \times SP_i$$

Remark: All the basic data, man-hours, spare parts and supply requirements, either fixed or variable, will be explicitly or implicitly functions of:

- age
- past maintenance
- conditions of utilization.

Overhead cost: OC_i ; will not be modelled any further. It will be assumed to be a given cost per year and per fleet item.

OC_i = overhead cost per year for type i flotilla.

Depreciation cost: For a flotilla of type i , it will have to be

broken into two components, because of different life-times:

• hull:

$$DC_{hi} = IC_{hi} \times CRF_{hi}$$

where:

DC_{hi} = depreciation cost for full per vessel of type i

$IC_{hi} = IC_{hi_1} + IC_{hi_2} + IC_{hi_3}$ = initial cost of hull

CRF_{hi} = capital recovery factor for hull.

• engine:

$$DC_{ei} = IC_{ei} \times CRF_{ei}$$

with the same notations.

Interest cost: can be modelled in this way:

$$IC = AV \times i$$

where: IC = interest charge per year

AV = average value of the fleet in operations (as a fraction of its initial cost)

i = interest rate.

Remark: The same remarks can be done about cost allocation as for railroads. Fleet allocation and Egyptian costing procedures will condition the adequate allocation process on a link basis.

b. Maintenance cost and deterioration of canals: Class I canals are maintained by the Ministry of Transport, except for irrigation structures. Class II canals are maintained by the Ministry of Irrigation.

Deterioration of canals has two major aspects:

- bank deterioration: It seems to be quite a problem in Egypt where bank protection is very inefficient. Although traffic has definitely an impact on bank deterioration it does not seem to be possible to quantify this relationship.

- material deposits: These result in extensive dredging particularly of the Upper Nile. The relationship between dredging requirements and actual loaded draft, or the rate of sedimentation can be used to compute adequate dredging operations.

Let us call DP the cost of dredging one m^3 . A given average loaded draft, or a given minimum loaded draft, LD, will imply a required dredged volume $V[LD]$. Consequently the dredging cost will be:

$$DC = DP \times V[LD] = DC[LD]$$

where: DC = dredging cost required to maintain LD.

Remark: The relationship can be expressed this way: $LD = LD[DC]$, if the actual loaded draft is viewed as a consequence of dredging operations.

For example (18), a continuous loaded draft of 1.8 m. on the Nile would require a total dredging of 25 million m³.

Good estimates of the functional relationship $V[LD]$ should be available, given geometrical characteristics, current velocity and a subsequent rate of sedimentation. So far bank protection costs are insignificant. Future maintenance costs have been estimated to 1% of the initial investment (18).

c. Maintenance and operating costs of locks: They are borne by the Ministry of Transport.

The disaggregation used in the National Transport Study (18) is the following:

operation, routine maintenance and labor costs:	LC_1
material cost:	LC_2
periodic maintenance:	LC_3

Therefore total lock costs per year are:

$$LC = LC_1 + LC_2 + LC_3$$

Individual costs, of course depend upon:

- crew-size

- gate operations (electrical, manual)
- actual traffic.

A more precise disaggregation could be tempted to try and identify flow-dependent lock cost components. Anyway the impact of actual flows does not seem to be very significant, if any exists.

(ii) Outputs.

The outputs of the model will be a set of costs related to users (trip-time, unreliability, loss and damage, rate), operators (fleet operating and maintenance costs) and the State, embodied by the Ministry of Transport (lock and canals operating and maintenance costs). Besides a framework has been defined for a study of deterioration, although modelling it in the case of waterway infrastructures seems hardly possible.

A study of investment policy, through its impacts upon the major inputs of the model, although beyond the scope of this thesis, can be done within this framework. It will be the last step of the modelling process as defined in Chapter II. A qualitative approach has been given in the first part of this chapter.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The purpose of a multi-modal intercity transportation model is to test a broad spectrum of policies related to investments concerning either the physical plant or the fleet, operational options, regulations and maintenance. The procedure used is the quantification of the fundamental relationships between the transportation system per se, the pattern of transport flows and the activity system, defined roughly as the socio-economic environment. Consequently such a model has to be:

- multi-modal: since obviously modal choices by users involve the whole spectrum of possibilities.
- through a multi-criteria evaluation since it has to deal with socio-economic phenomena.
- policy sensitive, because of its basic purpose.

Now a literature review showed that policy sensitivity had two major necessary components:

- the explicit incorporation of policy sensitive variables.
- an analytical way of quantifying the impacts of various policies upon transportation activities.

So far, most attempts to build policy-sensitive models lacked this

second characteristic. The way of dealing with policies was to change the values of user-specified level of service attributes. The procedure used involved a great deal of trial and error approaches. Now the main criteria to classify policy issues appeared to be:

- modellability
- implicitness
- relation to the transport sector
- relation to transportation planning authorities within the the decision-making process.

The preliminary step to the equilibration procedure on the multi-modal network has to be a careful unimodal analysis, because of specific features of each mode. The purpose of this analysis is twofold:

- On one hand, through a simulation process, to decompose operations into basic components, for which both inputs and outputs can be accurately quantified. Then these components have to be related to unit costs. Besides, the level of performance of the transportation system has to be evaluated in terms of user's costs: trip-time, unreliability, loss and damage.

- On the other hand, to provide a general framework for a detailed link analysis, once flows have been determined through an equilibration procedure. This analysis has four main focuses:

- investment needs to meet demand and deterioration
- accounting: determination of profits and losses

- deterioration
- subsequent maintenance needs, in addition to routine works.

The unimodal analysis will use inputs related to five major areas:

- investment policy
- technology
- regulations
- organization
- present network condition.

The analytical tool will be the generalized cost function. It will be related to a combination of mode, link, commodity and possibly user-group. The equilibration procedure, based on entropy maximization and cost minimization, will use it as a basic input. The generalized cost-function will be impacted by investment policy, market regulations and operating regulations. Its two major components are:

- either the fraction of operator's costs which are charged upon users, or an exogenously imposed price for the transportation service considered.
- user's costs in terms of trip-time, reliability and loss and damage.

Although a general framework for a detailed link analysis is provided by this study, this second step of unimodal studies has not been dealt with in this thesis. The analysis of deterioration and capital expenditures

will be the following task of the multi-modal research.

Now a literature review showed that there were two basic approaches to operator's costs:

- one based on economic theory: the provision of a production function and of a set of input prices, theoretically allows to compute either a long-term (variable capital input) or a short-term (fixed capital input) cost-function.

- another one based on a simulation process of transportation operations, and the derivation of subsequent costs. This is what we called an engineering approach.

The difficulty of deriving an accurate production function, behavioral as well as statistical stumbling blocks led to use the latter approach. Moreover it allowed to incorporate as many policy-sensitive variables as compatible with data requirements and the existence of relevant analytical relationships. In any case, regression analysis always provides a tool to quantify intuitively likely relationships.

As regards users' costs, three major areas were investigated:

- trip-time, as expressed by average data. A dollar value of time, as determined by several statistical devices, allows to relate it to an actual monetary cost.

- reliability, as expressed by any indicator of the way the trip-time distribution over a link is spread around its mean. Two basic costs were related to reliability: a stock-out cost, which is a function of the type of firm considered and a safety stock capital carrying cost.

- loss and damage: according to the liability of carriers this cost was a fraction of the total value of lost goods.

As regards mode-specific studies related to railroads and inland waterways transportations, a common basic framework was used. It was designed so as to leave a sufficient flexibility to potential users of the model, according to data availability and specific situations. Several parts are optional and can be replaced by mere extrapolation of historical data. The basic steps of the approach chosen are:

- A study of the existing situation of the two unimodal transportation systems. It aimed at pointing from a qualitative point of view, the impacts upon costs and flows of:

- investment issues: related either to the physical plant or to the fleets.
- operating regulations and options.
- existing but non-modellable miscellaneous issues: because of the basic scale of unimodal studies they were mainly related to phenomena which were not directly connected with link-level data.

- The following step was elaborate a set of autonomous submodels, corresponding to the following specific areas:

- trip-time: it was broken, in turn, into two major components: on one hand linehaul segment time, on the other hand terminal (yard or lock) time.
- fuel consumption.
- unreliability cost, namely stock out costs.
- fleet requirements: expressed as a function of actual demand and vehicle availability. The latter was modelled according to the notion of serviceable age and subsequent maintenance needs and typical lay-days.
- rates: when their complexity or a lack of data imply either modelling or simplifying the actual tariff structure.

The major inputs of unimodal models were related to three main areas, in addition to the results of submodel computations:

- links: in terms of operating options and physical characteristics;
- vehicles: in terms of performance and availability;
- commodities: in terms of general attributes and specific transportation requirements.

Further internal computations aimed at deriving global costs from physical amounts, on one hand, at computing maintenance and operating

costs on the other hand.

The basic output of this first unimodal study was a set of costs for operators, owners and users. A permeability constant, as defined in Chapter II allows to compute the actual generalized link costs, which will be used in the equilibration procedure.

The further steps of the multi-modal study should be the actual data gathering and calibration of the various submodels involved. Besides, although a general framework was sketched, the detailed link analysis will have to be expanded and designed, so as to deal with capital expenditures and a detailed deterioration modelling, provided it is actually feasible.

Hopefully the framework designed in this thesis is very flexible and leaves a crucial part to users as regards the level of disaggregation of the analysis of transportation unimodal activities. The final quantification of the proposed analytical relationships will be conditioned by a crucial tradeoff between policy sensitive modelling on one hand, and computational ease, data requirements and analytical accuracy on the other hand. Its detailed form heavily depends upon the precise spectrum of policies which have to be dealt with and the subsequent variables which have to be incorporated.

APPENDIX A

TRANSPORTATION REGULATIONS

(i) Market Regulations

1. Entry Regulations

- Licensing
- Concession of operating authority
- Entry capital requirements
- Entry minimum service requirements
- Entry market link requirements
- Private/public share distribution requirements

2. Exit Regulations

- Obligations under operating authority
- Exit market link requirements
- Nationalization alternative
- Exit minimum service requirements

3. Price Regulations

- Exogenously determined fixed price level
- Cost-related level of prices linked to rate of return regulation
- Free price linked to parametric profit tax levels determined by rate of return regulation
- Cross subsidization of markets

- Exogenously determined fixed price level with negative profit linked to subsidy level determined by rate of return regulation

4. Taxes and Subsidies

- Taxes and subsidies applied to profit component linked to rate of return regulation
- Taxes and subsidies on specific inputs
- Taxes and subsidies on specific markets (vector: link, mode, commodity)
- Taxes and subsidies on specific modes

5. Rate of Return Regulation

- Minimum guaranteed rate of return coupled with appropriate subsidy levels at the company, market (vector: link, mode, commodity) commodity level
- Maximum permitted rate of return coupled with appropriate tax levels on profits
- Minimum guaranteed/maximum permitted rate of return coupled with appropriate tax cum subsidy structure.

(ii) Operating Regulations

1. Service Regulations

- Obligation to provide service to specific points even under unprofitable circumstances
- Minimum frequency of service standards
- Minimum quality of service requirements (time, time reliability, product deterioration standards, etc.)

- Maximum speed
- Maximum load factor
- Minimum adherence to schedule
- Maximum Weight limit

2. Equipment Regulation

- Minimum power requirements
- Equipment safety standards
- Maximum weight limit
- Minimum maintenance requirements
- Age limitations

3. Labor Regulations

- Minimum wages
- Minimum crew requirements
- Maximum time limitations
- Labor safety standards
- Labor force structure

4. Environmental Regulations

- Fuel emission standards
- Noise level standards
- Soil or water deterioration standards

(iii) Modal Operating Regulations

1. Railroads

Service Regulations

- Minimum frequency of trains standards

- Minimum time reliability standards
- Maximum commodity load factors
- Number of cars per train
- Maximum speed
- Number of locomotives per train standards
- Power to weight ratio requirements
- Maximum weight limits

Equipment Regulations

- Minimum power requirements for locomotives
- Railroad car specifications
- Maintenance of equipment standards
 - Locomotives
 - Cars
- Equipment safety standards
 - Safety specifications for locomotives
 - Safety specifications for cars
 - Safety specifications for signalling
 - Age limitations of locomotives and cars
- Maintenance of right-of-way standards

Labor Regulations

- Minimum crew wages
- Minimum helper's wages
- Minimum maintenance and clerical personnel wages
- Minimum loading/unloading crew requirements
- Maximum working time limitations
- Labor safety standards

Environmental Regulations

- Fuel emission standards
- Limitations on quality of fuel
- Noise level standards in urban areas

2. Trucking

Service Regulations

- Minimum frequency of service standards
- Minimum time reliability standards
- Maximum commodity load factors
- Maximum allowed speed per link
- Maximum weight limits
- Maximum axle load limitations

Equipment Regulations

- Truck specifications
- Maintenance of truck standards
- Equipment of safety standards
 - Safety specifications for trucks
 - Safety specifications for operation
 - Age limitation for trucks

Labor Regulations

- Minimum crew wages
- Minimum helper's wages
- Minimum maintenance and clerical personnel wages
- Minimum crew requirements
- Minimum loading/unloading requirements

- Maximum working time limitations
- Labor safety standards

Environmental Regulations

- Fuel emission standards
- Limitations on fuel characteristics

3. Waterways

Service Regulations

- Minimum frequency of service
- Minimum time reliability standards
- Maximum commodity load factors
- Minimum power requirements
- Maximum loaded draft

Equipment Regulations

- Minimum power requirements
- Specifications for barges (length, width, draft, height)
- Maintenance of equipment standards
- Equipment safety standards
 - engine
 - signalization
 - navigation equipment
- Age limitations on equipment

Labor Regulations

- Minimum crew wages
- Minimum helper's wages

- Minimum maintenance and clerical personnel wages
- Minimum ship crew requirements
- Minimum loading/unloading crew requirements
- Maximum working time limitations
- Labor safety standards

Environmental Regulations

- Fuel emission standards
- Fuel characteristics standards
- Water pollution standards

APPENDIX B

The equilibrium tow-speed relative to the water, S^* can be determined through solving the following set of equations (25):

$$S^* = -1.14 \times HP + [1.3(HP)^2 - 4 \times d \times (-1)^{d+1} \times RDRAG - 31.82 \times HP + 0.0039 \times (HP)^2 - 0.38 \times HP \times D]^{0.5/2\beta}$$

where the drag resistance RDRAG is:

$$RDRAG = 0.0086 \times S_w^2 \times D^{-1.33} \times (52 + 0.44 - H) \times H \times L \times B + 24,300 + 350 \times HP - 0.021(HP)^2$$

The coefficient β is defined as:

$$\beta = 0.07289 \times \exp[1.46/D-H] \times H^{(0.6+50/W-B)} \times L^{0.38} \times B^{1.19} + 172.$$

where:

- HP = horsepower of the tow-boat
- d = 0 for downstream, 1 for upstream
- D = depth of canal
- S_w = stream current
- H = draft of the flotilla
- L = length of the flotilla
- B = breadth of the flotilla
- W = width of the canal.

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